The Nature Conservancy®

Gulf Coastal Plain Ecosystem Partnership

APPENDIX G.

Gulf Coastal Plain Ecosystem Partnership

Steering Committee Meeting # 3

Jackson Guard, Eglin Air Force Base
December 2-3, 1999

Research, Scientific and General Information

Public Education
Aquatic Woody Debris
Flatwoods Salamander
Herbicides
Longleaf Alliance

Champion International • 4025 Highway 178 • Jay, Florida 32565 • 850 675-5760 • FAX 850 675-5756

Gulf Coastal Plain Ecosystem Partnership Meeting
December 2 - 3, 1999
Jackson Guard, Eglin Air Force Base

Agenda (all times are Central)

DECEMBER 2, 1999

Time	**Topic**
9:00 am	Welcome & Meeting Logistics
9:10 am	Introduction of Partner Contacts
	GCPEP Operations
9:25 am	Discussion on Adding New Partners
10:15 am	Break
10:30 am	Job Objectives & Expectations for Project Director
11:10 am	Discussion on GCPEP Co-Director
11:30 am	GCPEP Aquatic Specialist Introduction
11:40 am	Expectations for Aquatic Specialist
12:00 pm	Lunch
12:45 pm	GCPEP Administrative Assistant Introduction
12:50 pm	Expectations for Administrative Assistant
	Major Project Updates
1:15 pm	Project Updates & Discussion
2:30 pm	Break
2:45 pm	Continue Project Updates & Discussion
3:55 pm	Wrap-up & Cover 12/3 Agenda
4:00 pm	End of Meeting for Day 1

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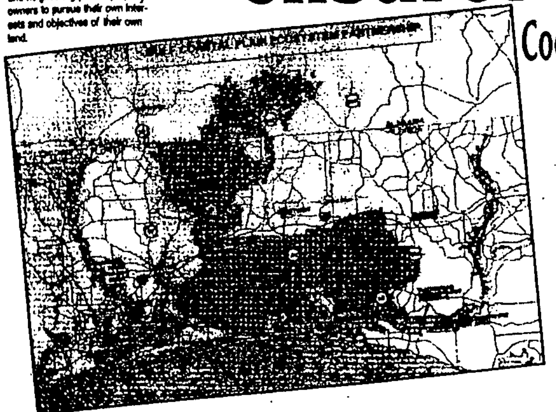
DECEMBER 3, 1999

Time	Topic
8:00 am	Welcome & Agenda
	Strategies and Actions Identification
8:10 am	Identify Strategies & Actions to Abate Threats
9:20 am	Break
	New Project Identification
9:30 am	Selection of Additional Projects
	Meeting Wrap-up
10:30 am	Partner Needs & Suggestions
10:40 am	Date Selection & Location for Next Meeting
10:50 am	Meeting Wrap-up & Evaluation
11:00 am	End of Meeting

Innovative partnership ensures protection

Because of map scale, map does not indicate all private property. The GCPEP partners recognize the full rights of individual land managers and neighboring private property owners to pursue their own interests and objectives of their own land.



Cooperation allows lands to be safeguarded, even as they are used

For Vernon Compton, 39, representing The Nature Conservancy is a dream come true and testament to his expansive knowledge of environmental conservation. As a youngster growing up in central Louisiana, his parents fostered a love for the intricate, and often unnoticed by the untrained eye, uniqueness of forest ecosystems. After graduating from LSU with a degree in Forest Management, Compton took a position with the Blackwater River State Forest and soon was promoted to resource administrator where he was in charge of timber management, endangered species, ecology and tree improvement and the communications center. In May 1998 he beat out a number of candidates from across the country, becoming The Nature Conservancy's Gulf Coastal Plain Ecosystem Partnership project director. He shares his love for the area's forests, which are very similar to the forests he traversed as a child, in his role as Florida Trail Association Western Gate Chapter's chairman.

Building relationships between landowners to bridge gaps in the Florida National Trail is just a small task among the many goals Vernon Compton oversees as The Nature Conservancy's Gulf Coastal Plain Ecosystem Partnership project director.

His focus is coordinating objectives of a collaboration of seven public and private entities that own vast portions of undeveloped land in the Florida Panhandle and south Alabama.

The partners, Eglin Air Force Base, Florida Division of Forestry, Northwest Florida Water Management District, National Forests in Alabama, Champion International Corp., The Nature Conservancy and National Forests in Florida, signed a memorandum of understanding in 1996 to voluntarily implement initiatives to conserve and restore the dwindling and rare ecosystems unique to their properties.

"Our partnership is innovative in that it involves public and private partners," Compton said. Such partnerships are becoming more common as a way to save tax dollars and resources while working on common goals.

Forging such a relationship is important, "Because problems don't stop and start at landowners' boundaries. Something like this can do greater good for the larger group of people who are all working on common issues."

Some of those issues include:

- Sustaining native plants and animals.
- Conserving and restoring the integrity of ecosystems.
- Ensuring a continued supply of forest commodities, recreational opportunities, clean water and ecosystems.
- Supporting the human communities that depend upon these resources and services.

Continued on Indy 8

Continued from Indy 7

The Land

All told, the partners own more than 845,800 acres spanning seven counties in two states, an area larger than the Great Smoky Mountains National Park.

The partnership landscape is very diverse biologically and a critical link in conserving the biodiversity of the Southeastern United States, Compton said.

"In fact, the East Gulf Coastal Plain, where the GCPEP landscape is located, is biologically one of the two to three richest areas in North America," he said. "Part of the reason for this is that this area has never been glaciated, and has been continuously occupied by plants and animals for a long period of time."

The Great Smoky Mountains has the most diverse ecosystem in the United States, but the partnership land is high on the list too. It's one of the most diverse and critical in terms of protecting plant and animal biodiversity in the Southeast.

"The landscape has a diversity of ecological systems, ranging from sand hills and rolling longleaf pine-dominated uplands to pine flatwoods and savannas, seepage bogs, bottomland hardwood forests, a barrier island and dune systems, and estuaries. In North America, this region is one of the true hotspots of biodiversity," he said.

The area is filled with some of the last remaining stands of old-growth longleaf pines, some as old as 400 to 600 years.

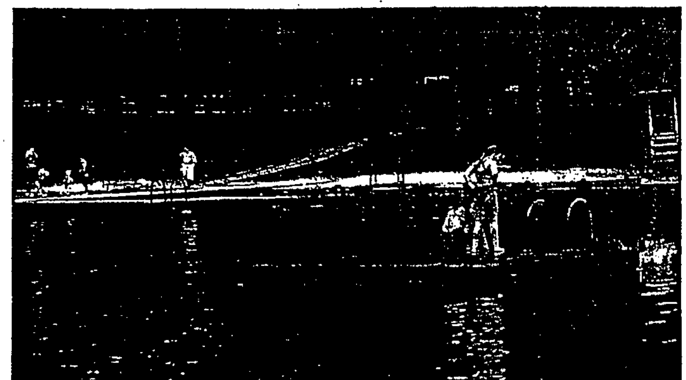
"More than 50 percent of old-growth pines remaining in the United States are at Eglin, which makes that area very special," Compton said, though many other features of the partnership land are unique.

Some 163 rare or imperiled plant, lichen, vertebrate and invertebrate species can be found on the partnership land. "Of these 16, and perhaps more, occur only within the partnership managed areas, and no where else in the world," Compton said.

The Blackwater River, which begins to the north in neighboring Conecuh County, Ala., and meanders 30 miles southwestward through the forest toward Blackwater Bay near Milton, is one of the few remaining shifting sand bottom streams still in its natural state. It should remain so for generations to come, as long as it buffered by landowners focused on its conservation.

Much of the river flows through Blackwater River State Forest, a diverse landscape of low rolling hills separated by meandering water courses and broad floodplains. Elevations within the forest range from 80 feet to 200 feet above sea level, surprising hills for those unfamiliar with the area just 40 minutes from Pensacola.

The partnership land also is filled with numerous pristine spring-fed rivers and creeks, some rarely traversed by humans, while others draw thousands of outdoor enthusiasts seeking aquatic diversions such as fishing, canoeing and kayaking.



A hot summer day draws visitors to spring-fed Krul Lake in Santa Rosa County.

Wildlife

While the area's wildlife may not be as exotic as Africa's lions or the Komodo dragons of the South Pacific, it's unique enough to attract the cable channel "Animal Planet's" hugely popular Crocodile Hunter and star wildlife expert Steve Irwin. Irwin and his crew were recently at Eglin filming a segment highlighting the base's environmental program and its stewardship of black bears and snakes.

The area also is home to endangered, threatened or sensitive wildlife, including the red cockaded woodpecker and the Okaloosa darter, a freshwater fish found only on Eglin Air Force Base.

"There's a number of species only found on partnership lands that you won't find anywhere in the world," Compton said. "The Florida bog frog, for instance, is found on a very small area of Eglin and Champion land."

Other rare species include the Santa Rosa beach mouse, Zigzag Blackwater River daddisfly and a plant called the hairy wild indigo. Champion is surveying its lands to determine if it has any threatened or endangered species, including the bog frog and flatlands salamander, said JoAnn McKeithan, Champion's community relations manager.

"We know we don't currently have the red cockaded woodpecker on our land. But they are nearby. We do know black bear are occasional visitors, so we work with hunting clubs to encourage their awareness of bears."

While the public may not know the difference between a bog frog and a toad, they certainly pay attention to things warm and fuzzy such as Florida Black Bears.

Eglin is home to one of the largest black bear populations in the state, estimated to be between 50 and 60, said Mike Spaits, Eglin's environmental affairs officer.

Graduate students from the universities of Florida and Tennessee just completed a four-year study of Eglin's bear population

Continued on Indy 9

Continued from Indy 8

A boardwalk at Sweetwater Trail that stretches between Krul and Bear lakes.

and successfully attached radio collars to 13 bears to track their lifestyles.

In recent years, some of those bears have wandered beyond Eglin boundaries into populated areas of South Santa Rosa County and Pensacola Beach. Wildlife specialists have always captured the wayward bears and returned them to Eglin.

A few bears can be found on Yellow River Water Management Area and Champion land. But it's unusual to find them in other areas of the partnership land, though it is suitable for them.

"It's a species that requires a large landscape area to be able to survive," said Compton, who views the partnership as a vital tool in helping black bear survive and thrive into the future.

Partnership

What makes the partnership so important is the fact that the landowners' properties, for the most part, form one of the largest contiguous ecological communities of its type in the world, Compton said.

The corridor spans from the Gulf to the forests of Alabama, with the exceptions of two of Northwest Florida's wWater wanagement areas on the Escambia River, and the Choctawhatchee River area which also includes The Nature Conservancy's 2,750 acres.

The partnership was forged in response to a loss of longleaf pine habitat across the Southeast and a desire by local land managers to share resources amid dwindling funds and increased demand for better information, resources and expertise.

"We try to share what works and what doesn't work and how to get it to work," Compton said. "We try to get the right people together to share ideas. There are those who may have expertise in certain areas, or have been to workshops, had extra training or be privy to certain information."

Champion wanted to participate in the partnership because it demonstrates its commitment to balance environmental concerns with timber management objectives, McKeithan said.

Partnering is not a new concept for Champion. It's forged similar relationships with other parts of its half million acres in its western region, which spans from Defuniak Springs to Mobile.

"We have partnerships with several agencies where we have agreed to manage and conserve the unique aspects of this forest," McKeithan said.

One of those partnerships is with The Nature Conservancy, U.S. Forest Service, Auburn University, Alabama Forestry Commission and Alabama Natural Heritage program to preserve 65 acres of virgin, old-growth longleaf pine stands in Flomaton, Ala. It is one of only five remaining virgin longleaf stands in the country and the only one in Alabama.

"If you drive on Highway 31 in Flomaton, you drive right through it," she said. "Some of the trees are 300 years old."

The concept of the partnership to share knowledge, skills and resources is what attracts Eglin, Spaits said, especially since the reservation manages the largest piece, 724 square miles of pristine land in Northwest Florida.

"It's a large chunk of land and it's a great resource," Spaits said. Most of the land is basically reserved as a safety buffer for the weapons testing.

"While the area of weapons impact is very small, the safety footprint is very large. It's necessary for safe testing of today's weapons," he said.

Many are unaware that when testing is not under way, much of the reservation is open to the public who buy recreational permits for many outdoor activities such as hunting, hiking, fishing, swimming, boating, camping or bird watching.

Permit prices vary depending on the activity and can be obtained by calling the permit office at 850-882-4164.

In fact, much of the partnership land is available for recreational use. The Blackwater River State Forest has nine camping areas, numerous trails systems, including horse trails, and a fairly new mountain bike trail around Bear Lake. The area is known as Florida's Canoe Capital for its numerous negotiable rivers and creeks and popular canoe liveries such as Adventures Unlimited, Bob's Canoes and Blackwater Canoe Rental & Sales.

Champion's recreational opportunities vary among its landholdings across the United States. "But our lands in this area are heavily used for hunting animals like deer and turkey," McKeithan said.

"Many of the canoeing streams flow through our property. Coldwater is an example," she said.

Objectives

Even though all the partners have diverse missions and objectives, ranging from intense forestry to military training, recreation and water resource protection and ecological restoration, they meet on common ground when it comes to the longleaf pine ecosystem and how to balance conservation with increased recreational needs brought on by an increasing interests in Ecotourism.

Worldwide, more people want to escape high-stress jobs and lifestyles for quiet vacations hiking, camping and canoeing. Demands for such nature excursions can stress and damage pristine areas if not managed correctly, Compton said.

Another consideration is maintaining and growing jobs which are dependent on natural resources important to the tax base of local counties, Compton said.

According to the Department of Forestry's 1996 data, some 3,200 people are directly employed in forestry jobs in Escambia County and another 8,960 jobs are indirectly impacted by the forestry industry. More than 800 jobs in Santa Rosa County are related to forestry.

Champión employs 1,100 locally in its mill, forestry and corporate functions and has another 800 retirees, many of whom remain in this area.

The partnership has conducted a number of cooperative efforts including siting the Florida National Scenic Trail and:

- Joint prescribed burns to restore important ecological areas and reduce chances of wildfires.
- Cooperative management of the endangered red cockaded woodpecker.
- Information exchange on forest management techniques and technology
- Tracking the status and location of rare plants and animals.

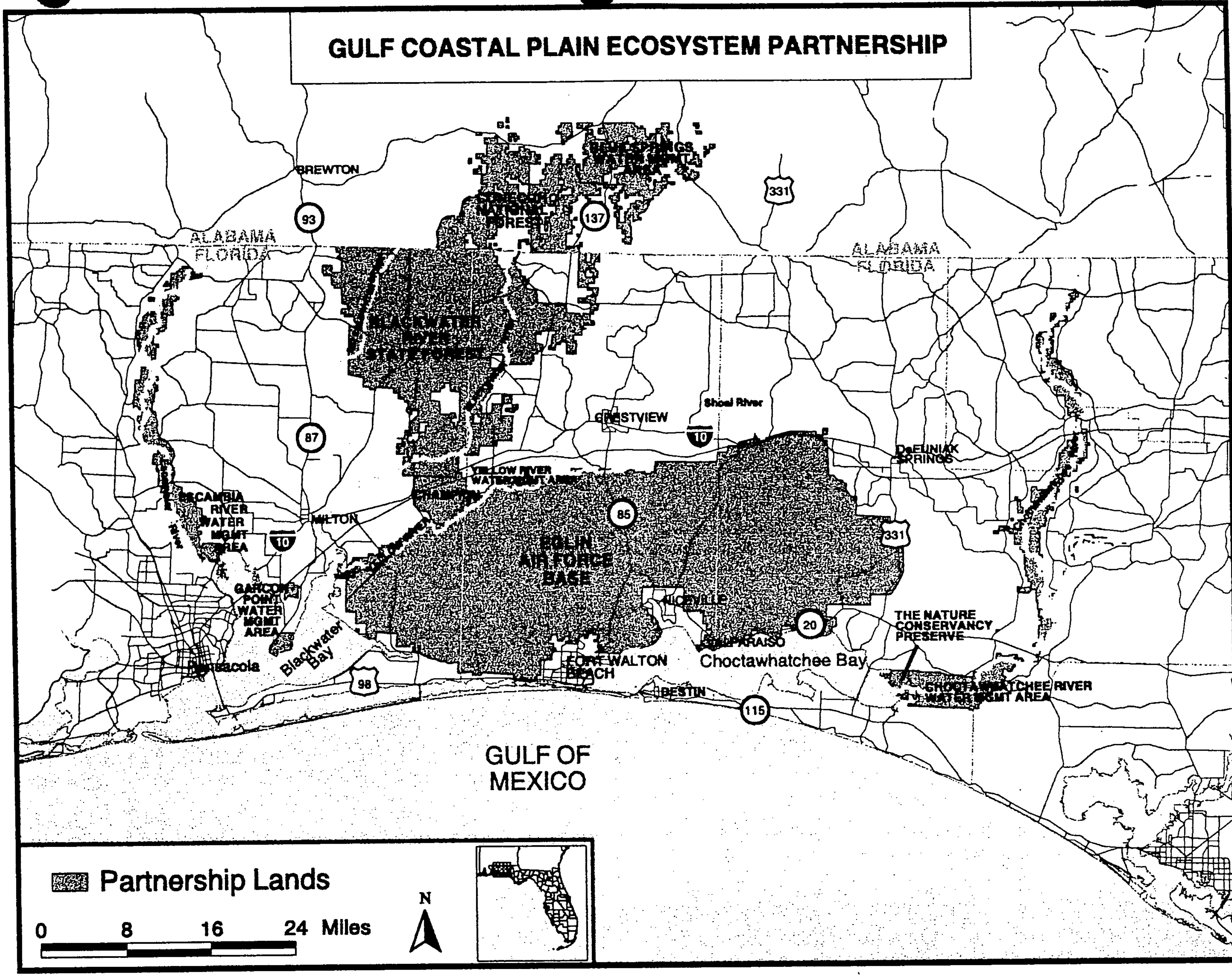
"The aquatic areas is where we are lacking the most. Like what we need to do with roads and bridges," Compton said.

Recent news that the state wants to close or restore hundreds of miles of dirt roads in the Blackwater River State Forest because of dirt and clay runoff, is an example of strides yet to be made, he said.

1800s grist mill that still works on the Sweetwater Trail near Krul Lake.

GULF COAST PLAIN ECOSYSTEM PARTERSHIP – PARTNER CONTACTS (as of November 29, 1999)

	CONTACT	ALTERNATE
Blackwater River State Forest	**Dennis Hardin** Phone: 850-414-8293 Fax: 850-488-0863 Florida Division of Forestry 3125 Conner Blvd. Tallahassee, FL 32399 Hardin@doacs.state.fl.us	**Tom Serviss** Phone: 850-957-6153 Fax: 850-957-6143 Florida Division of Forestry 11650 Munson Highway Milton, FL 32570 Servist@doacs.state.fl.us
Champion International	**Arden Shropshire** Phone: 850-675-0929 ext. 113 Fax: 850-675-0938 Champion International Corporation 4025 Highway 178 Jay, FL 32565 Shrop@champint.com	**Ad Platt** Phone: 850-937-4830 Fax: 850-968-3027 Champion International Corporation P. O Box 875 Cantonment, FL 32533-0875 platta@champint.com
Conecuh National Forest	**Rick Lint** Phone: 334-222-2555 Fax: 334-222-6485 Conecuh National Forest Rt. 5, Box 157 Andalusia, AL 36420 Lint_Rick/r8_al_conecuh@fs.fed.us	**Gary Taylor** Phone: 334-222-2555 Fax: 334-222-6485 Conecuh National Forest Rt. 5, Box 157 Andalusia, AL 36420 Gtaylor/r8_al_conecuh@fs.fed.us
Eglin Air Force Base	**Rick McWhite** Phone: 850-882-4164 ext. 301 Fax: 850-882-5321 Natural Resources 107 Highway 85 North Niceville, FL 32578 Mcwhiter@ntserver.eglin.af.mil	**Carl Petrick** Phone: 850-882-4164 ext. 307 Fax: 850-882-5321 Natural Resources 107 Highway 85 North Niceville, FL 32578 petrickc@ntserver.eglin.af.mil
National Forests in Florida	**Andy Colaninno** Phone: 850-643-2282 Fax: 850-643-2284 National Forests in Florida P. O. Box 579 Bristol, FL 32321 Colaninno_Andrew/r8_fl_apalachicola@fs.fed.us	**Art Rohrbacher** / **Kathleen Atkinson** Phone: 850-942-9300 / 850-942-9347 Fax: 850-942-9305 / 850-942-9305 National Forests in Florida 325 John Knox Rd. Suite F100 Tallahassee, FL 32303 Rohrbacher_Art/r8_fl@fs.fed.us Katkinson/r8_fl@fs.fed.us
NW Florida Water Management District	**Steve Brown** Phone: 850-484-5125 Fax: 850-484-5133 NW FL Water Mgmt. District 2261 W. Nine Mile Rd. Pensacola, Fl 32534-9416 Steve.brown@nwfwmd.state.fl.us	**John Valenta** Phone: 850-482-9522 Fax: 850-482-9522 NW FL Water Mgmt. District 4765 Pelt Street Marianna, Fl 32446 John.valenta@nwfwmd.state.fl.us
The Nature Conservancy	**Jim Murrian** Phone: 407-682-3664 Fax: 407-682-3077 The Nature Conservancy 222 S. Westmonte Drive Suite 300 Altamonte Springs, FL 32714-4269 Jmurrian@tnc.org	**Larry Ellis** Phone: 334-865-5244 Fax: 334-865-9225 The Nature Conservancy P. O. Box 307 12475 Highway 90 Grand Bay, AL 36541 larry_ellis@tnc.org
PROJECT DIRECTOR	**Vernon Compton** Phone: 850-675-5760 Fax: 850-675-5756 Gulf Coast Plain Ecosystem Partnership P. O. Box 785 Milton, FL 32572-0785	Fed Ex/UPS Address: Vernon Compton-The Nature Conservancy c/o Champion International 4025 Highway 178 Jay, FL 32565 email: gcpep@bellsouth.net


GULF COASTAL PLAIN ECOSYSTEM PARTNERSHIP
BREWTON
93
137
331
ALABAMA
FLORIDA
87
CRESTVIEW
Shoal River
10
DeFUNIAK SPRINGS
YELLOW RIVER WATER MGMT AREA
ESCAMBIA RIVER WATER MGMT AREA
MILTON
85
EGLIN AIR FORCE BASE
GARCON POINT WATER MGMT AREA
NICEVILLE
20
THE NATURE CONSERVANCY PRESERVE
Blackwater Bay
FORT WALTON BEACH
Choctawhatchee Bay
Pensacola
98
DESTIN
115
CHOCTAWHATCHEE RIVER WATER MGMT AREA
GULF OF MEXICO
Partnership Lands
0 8 16 24 Miles
N

Gulf Coast Plain Ecosystem Partnership (GCPEP)
Major Projects Addressing Key Strategies
from June 22 – 23, 1999 Steering Committee Meeting

1. Pursue Choctawhatchee National Forest land exchange or sale. Chris Zajeck of Apalachicola National Forest in Tallahassee will be the point person. Also involve Conecuh National Forest, Eglin Air Force Base, the Alabama Heritage Program, and George Willson of The Nature Conservancy.

2. Each partner identify critical parcels for land management or protection of conservation targets. Complete a map and state why the parcel was selected. Complete by September 30, 1999.

3. Pursue public opinion poll. Project Director to discuss with TNC Government Relations and Gary Taylor of Conecuh National Forest. Jeff Hardesty (TNC) to discuss with Susan Jacobsen (University of Florida). Funding to be committed by October 1, 1999.

4. Finish fire model for Blackwater River State Forest and Conecuh National Forest. Host workshop for stakeholders. Rick Lint to provide Conecuh map. Project Director to provide needed information to Garry Peterson.

5. Project Director to approach Alabama and Florida Natural Heritage Inventory programs and DEP Ecosystem Management Coordinators for possibility of producing target maps for GCPEP.

6. GCPEP Burn Team to review and possibly pursue funding from National Turkey Federation. Team to include James Furman (Coordinator) from Eglin Air Force Base, Sonny Greene from Blackwater River State Forest, Pat Brinn or Michael Heard from Conecuh National Forest, and Steve Brown from the Northwest Florida Water Management District. Recommendations to be made by September 30, 1999.

7. Compile report on herbicide impacts on groundcover in the longleaf pine ecosystem. The Longleaf Pine Restoration Project at Eglin Air Force Base will complete by December 30, 1999.

8. Complete assessment of aquatic systems status. Rick McWhite of Eglin Air Force Base will take the lead on developing a rapid assessment technique. Team to assist will include Kevin Leftwich of the National Forests in Alabama, Joe DiVivo of Eglin Air Force Base, and the GCPEP Aquatic Specialist.

GCPEP STRATEGIES AND ACTIONS

Source of Stress	Strategies and Actions
Incompatible residential and commercial adjacent development	• Each partner must identify specific purposes and needs for acquisition of land. Of these, identify most threatened. End product should be a map. • Identify parcels already on acquisition lists. • Identify most desirable parcels for acquisition to protect buffers. • Identify mechanisms, partners, and funding for acquisition. • Use the sale of Choctawhatchee National Forest lands near Eglin for funding to acquire Conecuh National Forest or Eglin acquisitions. • National Forests in Florida and Alabama, The Nature Conservancy, and Eglin work on mechanisms for sale of Choctawhatchee National Forest lands.
Inadequate/unstable funding	• Learn outcome of Florida Governors Report on Prescribed Burning. • Cooperate with Pensacola Bay Ecosystem Management Advisory Council for FEMA funding for road and erosion control projects. • Pursue external funding of $10,000 for helicopter prescribed burning assistance. • Establish GCPEP burn crew (10 people, 6 months/year ?). • Pursue GCPEP targets inventory funding. Funding to possibly come from non-game grant, TNC, USFWS, USFS cost share, Champion, DEP, National Council for Air & Stream Improvement, and EPA. • Project Director to interview partners on target lists and inventory needs. Aquatic Ecologist at Eglin to interview partners on aquatic inventory needs. • Project Director and TNC staff to develop list of funding sources for conducting conservation target inventories on partner lands.
Incompatible fire management	• Consider a public opinion poll and/or focus groups to craft a pro-fire message for stakeholders and the general public. • Contact the Florida Division of Forestry, the Governors Council on Fire and the North Florida Prescribed Fire Council on public education and/or polling after the 1998 Florida wildfires. • Work with Garry Peterson to complete the fire model for Blackwater River State Forest and Conecuh National Forest. • Assist Eglin Air Force Base with Cape San Blas burn.
Incompatible silviculture and land management practices	• Hire graduate student to compile information on herbicide/mechanical site preparation and ground cover. • Partners send available aquatic inventory information to Project Director to compile and send to GCPEP. • Arrange tour or workshop looking at herbicide rates, longleaf pine restoration and groundcover composition. Tour may include Eglin Air Force Base, Longleaf Pine Project, Blackwater River State Forest and Conecuh National Forest. Workshop to cover longleaf pine restoration and species composition goals. • Christina Kennedy from Duke University to provide land cover mapping information. • Compile information on longleaf pine growth and yield model. Discuss cooperating on this project with the Longleaf Alliance.
Roads and utility corridors	• Partners to pursue info on laws related to road BMP's from the Department of Environmental Protection and the Northwest Florida Water Management District. • Pursue funding for demonstration projects, BMP development and outreach person to work with counties. • Complete report on GCPEP roads, erosion, and impacts. Report to be presented to the Bay Area Resource Council.

Gulf Coast Plain Ecosystem Partnership (GCPEP)
New Partner Criteria

1. Understand and support the purposes of GCPEP and can clearly articulate their organization's contribution to the partnership.

2. Own substantial land or water holdings in the immediate GCPEP area, or be the lead management agency for government lands, with strong preference given to those sharing a border with one or more existing GCPEP partners.

3. Can offer significant expertise in one or more of the following management or conservation disciplines: forestry, water and watersheds, wildlife, biodiversity, prescribed fire, endangered species, or recreation.

4. Commit to sending at least one and preferably two representative to all GCPEP steering committee meetings.

5. Agree to take lead responsibility on one or more cooperative projects per year.

6. Agree to provide financial support to the partnership, either as direct funds or as in-kind support, and to seek additional funding for cooperative projects.

7. Agree to adhere to the basic GCPEP operating guidelines.

8. Agree to keep all appropriate people within their organization informed and knowledgable about GCPEP purposes and activities

GCPEP
by New Partner Criteria Committee
Arden Shropshire, Champion International
Jeff Hardesty, The Nature Conservancy

DRAFT

Conference on Communication and Environment

Negotiating Messages and Building on Experience: Wildland Fire in Florida's Interface

Martha C. Monroe
School of Forest Resources and Conservation
Susan K. Jacobson
Department of Wildlife Resources and Conservation
University of Florida

Abstract
Florida's devastating wildfires in the summer of 1998 spawned a variety of educational messages and programs about wildfire preparedness, wildfire prevention, and prescribed fire. Our program, funded by a grant from the Advisory Council for Environmental Education of the Florida Fish and Wildlife Conservation Commission, will ultimately develop a resource kit for County Extension Agents and Division of Forestry representatives to use in conducting local programs. The program development process has raised and answered several key questions: What should the public do to protect their homes from wildfire? What does the public already know and believe about wildland fire? What impact does experience with wildland fire have on knowledge and attitudes about fire?

The Background

Florida is a subtropical peninsula between the Gulf of Mexico and the Atlantic Ocean. The geology and climate have shaped native ecosystems that thrive in seasons of high temperatures, high humidity, and frequent fire. Most of Florida's ecosystems are characterized by plants and animals adapted to periodic (sometimes every 2-5 years), low-intensity, wildland fire. Daily summer thunderstorms, the product of clashing air masses that rise and move inland from the water, generate more cloud to ground lightning strikes than in any other location in the United States. Prior to human occupation, lightning started fires every year. In the last 50 years, however, a growing forest industry and increasing human population sponsored a policy of fire suppression. The inevitable build-up of vegetation has created natural areas across the state that will burn when the weather conditions are right.

In the summer of 1998, a severe drought and unusual wind patterns created the right conditions for fire. In less than 2 months, wildfires burned nearly 500,000 acres and damaged or destroyed 330 homes and businesses in Florida. Losses totaled over $800 million dollars. This catastrophe was an excellent opportunity for agencies to launch information, education, and communication campaigns to send a variety of messages: what citizens should do to manage their yard and landscape to reduce the threat of wildfire; why fires are "normal" in Florida; and how a more aggressive regime of prescribed fire can protect their homes.

The Cooperative Extension Service at the University of Florida is one of these agencies working to develop appropriate messages for the citizenry. Because this is a topic of complexity, uncertainty, and risk, our first question was "what should that message be?" The more typical program development questions, such as, "what does the audience know and believe?" and "how does the audience vary?" followed. This presentation will outline the process we used to get answers, and the answers we discovered.

Defining the Message

It is our observation that when multiple agencies are involved with a complex, uncertain, and risky environmental issue, each agency tends to retreat to their home turf and provide a message that is at the core of their mission, whether or not it contributes to the solution. So in the case of Florida's wildland fires, the Division of Forestry and other fire protection services used the traditional "defensible space" message that has been developed for the western wildland-urban interface:

- clear trees, brush, and flammable items from a 30 to 50' radius around homes; within this region, flames could be more easily stalled or stopped, thus protecting the house;
- lawns and shrubbery are to be well watered during the fire season, as green vegetation is less likely to burn;
- beyond the defensible space, thin trees based on slopes and plant less-flammable species.

Other state agencies and organizations, however, have very different guidelines and recommendations for the Florida homeowner. The Water Management Districts, for example, encourage people to plant xeric species and reduce the irrigation regime for their lawn in the summer. The Florida Solar Energy Center encourages homeowners to plant trees near their home for shade. The Fish and Wildlife Conservation Commission instructs people to plant continuous layers of shrubs to bring birds and other wildlife into their backyard. The Native Plant Society prefers that residents landscape with palmettos and wax myrtle – native plants that burn readily when ignited. All of these recommendations conflict with defensible space guidelines.

This confusion was particularly real for the County Extension Agents, who at various times, wear all these hats. This one agency has horticulture, water conservation, wildlife, energy conservation, and forestry specialists. For some individuals, however, the issue was not confusion but refusal and defiance. Faculty were heard to say, "if we tell people to clear trees from around their house, we'll destroy all the hard work we've done to help them create environmentally appropriate landscapes." The conflicting values and priorities raised with fire made the development of communication materials difficult yet vitally important. Citizens who feel strongly about one environmental value may ignore all information about defensible space, putting their homes and neighborhoods at risk should a wildfire approach.

Under the assumption that a defensible space message in Florida might be different from the western states' version, the Cooperative Extension Service launched a process to bring together representatives of all agencies and organizations that have landscaping messages for Florida homeowners. Participants were asked to work together to create a common message about home landscaping to help homeowners protect their landscape from wildfire. All participants were encouraged to use portions of this message in their relevant literature.

The Process

The key to the working meeting was getting a commitment from the right people in each organization. Knowing that they are all busy people, we developed the invitation letter to emphasize the importance of their input, the value of the project, and the problems with the traditional defensible space message. The following strategies were used to make this workshop a success:

- Personal phone calls to schedule the date;
- The Director's letterhead to get their attention;
- An engaging, interactive agenda that allowed everyone to speak to the full assembly and work in small groups to craft messages;
- Free parking and free lunch in a beautiful wooded retreat center;
- Quick replies to their comments and several sets of drafts of the publication.

A total of 24 individuals from 17 different agencies and organizations attended the working meeting. After a presentation about the 1998 fires, general discussion followed to better understand what fire fighters need from the public and what else the public should know or do to wisely manage their landscape. Unexpectedly, the group generated information about what developers, landscape architects, and planners should do to protect communities from wildland fire.

The discussion made clear that not everyone is at risk of wildfire, and only those at risk should landscape for defensible space. Rather than clearing defensible space, we were able to agree that homeowners should make sure fire trucks could get to and turn around at their home, remove ladder fuels, and keep certain native plants that explode during combustion from their home. It became clear to everyone that it is important to balance the risks of wildfire with the costs to the environment, recognizing that for those in a fire-prone area who are at substantial risk, some landscaping changes would be the prudent choice. A brochure for the public about landscaping tips and a fact sheet for planners and developers are in production.

Assessing the Audience

A telephone survey of 675 rural and suburban residents of North and Central Florida was conducted to provide direction for the development of the fire education program. The survey was created, reviewed, revised, and pilot tested by a team representing several agencies. The final survey included a total of 60 questions covering knowledge, attitude, intention, and demographics. The Bureau of Economic and Business Research (BEBR), University of Florida administered the survey in April, 1999 with a trained telephone survey research crew by randomly dialing Florida households. The sampling frame excluded Type I and Type II Metropolitan Statistical

Areas (MSAs) and south Florida counties because the target audience for the grant-funded program was rural and suburban residents in north and central Florida. We oversampled residents of high-fire counties (more than 10,000 acres burned in 1998) to have more respondents with fire experience. These responses were backweighted to enable us to generalize to the population. Data were analyzed with Statistica package for Windows (StatSoft, Inc., 1995).

Demographic Summary

The respondents in our sample are 43% male and 57% female and range in age from 18 to 90 years, for an average of 48 years. Although the sampling procedure focused on rural and suburban residents of Florida, 45% of respondents believe they live in a rural area, 36% in a suburban area, and 16% in an urban area. Regarding education, 31% of the respondents have only a high school degree, 32% have some college and 16% have a four-year degree. Only 12% of the sample have attended graduate school. Regarding ethnicity, 86% are white, 6% are black, and 2% are Hispanic. Nearly a quarter (24%) of the respondents worked in agricultural or natural resource professions at some time in their life.

The respondents have various degrees of experience with wildland fire. They live an average of 7.2 miles from a natural area; 78% say their natural area has pine trees. When asked if this natural area has burned since they have lived at this location, 30% said yes. More than half the sample (58%) smelled smoke at their homes during the 1998 fires for an average of 8 days. Only 3% were evacuated due to the wildfires, but 38.5% of the respondents say the fire was near their home (on average, 10 miles away). Despite this proximity and potential risk, 45% of the respondents were unconcerned about wildfire during the 1998 fire season, though 28% were very concerned.

Knowledge and Awareness Summary

A majority of the respondents had an accurate understanding of fire in Florida. Table 1 summarizes the results of the knowledge-based questions. Over 70% of the respondents know that fire plays a natural part in renewing and maintaining Florida's natural areas and that human carelessness now causes more fires than lightning. Fewer respondents knew the definition of prescribed fire, only 63% of the sample. In studies of the entire population of Florida, only 40% answered correctly. Only 67% of the respondents believe that fire also helps restore and maintain wildlife habitat.

Table 1. Percentage of respondents answering fire knowledge questions (n=662)

Question	Correct	Incorrect	DK*	NA**
Fire helps to renew forests.	79	16	5	<1
Periodic fire is a natural process in Florida.	76	19	5	<1
Human carelessness causes more fires in Florida than lightning.	75	16	8	1
Florida's natural areas will remain the same without fire.	70	24	6	<1
Natural areas that are burned every few years are useless as wildlife habitat.	67	27	6	<1
Prescribed fire is when land managers purposefully set a fire.	63	24	12	1

* Don't Know

** Not Available

Attitude Summary

Respondents shared somewhat mixed views about wildland fire in Florida. A majority of respondents believe that it is beneficial (60%), and a slim majority (56%) think that local wildlands should be periodically burned. Although just over half of respondents (53%) favor protecting air quality more than burning natural areas, a large majority (79%) believe residents who live near natural areas should tolerate more smoke (see Table 2).

Table 2. Percentage of respondents agreeing with fire statements (n=662)

Question	Agree	Disagree	Neutral	DK	NA
People who live near natural areas may have to tolerate some smoke from fires.	79	17	3	1	<1
Fire is beneficial to Florida's native plants.	60	28	6	5	1
The natural areas in my county should be burned periodically.	56	31	8	4	1
Protecting air quality is more important than burning natural areas.	53	31	10	5	1

A variety of questions asked respondents to consider the risks and benefits of prescribed fire (Tables 3 and 4). Residents' greatest concerns are for harm to wild animals and the spread of prescribed fires to neighboring property. They believe the greatest benefits of prescribed fire are wildfire prevention and improving land for forestry and grazing.

Table 3. Percentage of respondents rating the risks of prescribed fire (n=662)

Question	Large	Medium	Small	DK	NA
Harm to wild animals	47	24	27	1	0
Spread of fire to nearby property	44	25	28	3	<1
Unattractive landscape right after	39	26	32	2	1
Health problems from smoke and ash	33	29	35	3	<1
More regulations for landowners	29	32	26	12	1
Car accidents due to smoke	19	28	49	2	1

Table 4. Percentage of respondents rating the benefits of prescribed fire (n=662)

Question	Large	Medium	Small	DK	NA
Prevention of wildfires	73	18	5	3	<1
Improved forestry and grazing land	59	25	12.5	3	<1
Better wildlife habitat	48	32	14	5	<1
Fewer insect pests	49	26	19	6	<1
Maintenance of natural landscape	46	35	15	2	<1

Likelihood of Taking Actions

A surprisingly high number of respondents claim to have already taken some actions to protect their homes from wildfire. Of the four actions mentioned, over 42% of the respondents say they have already trimmed shrubs and branches and moved flammable materials away from their homes. Nearly half of the respondents claim to be likely to replace flammable building materials (47%) and use less flammable landscape plants (48%) (see Table 5).

Table 5. Percentage of respondents stating the likelihood of taking actions to protect their home from wildfire by... (n=662)

Question	Likely	Unlikely	Already	DK	NA
Removing shrubs and branches near your home	31	20	44	1	4
Moving flammable materials such as wood piles away from the home.	40	10	42	<1	7
Using landscape plants less likely to burn.	48	21	19	6	6
Replacing flammable building materials.	47	29	17	3	5

Discussion

There is a somewhat schizophrenic perspective on fire in Florida. People know it is good for natural areas, they think nearby residents should tolerate smoke, and they know prescribed fire is "better" than wildfire for a variety of reasons, but they want stricter controls on burning and they value air quality more than burning. Thus, future programs should recognize what most people already know and emphasize the importance of more novel benefits. Air quality concerns should be acknowledged as well as the efforts that are being taken to mitigate problems.

There may be some confusion about wildfire and prescribed fire, as only 63% of the population correctly identified the definition of prescribed fire, 25% answered incorrectly, and the remainder didn't know the answer. Although 37% (those who answered incorrectly or didn't know) is less than half the population, this is a large minority who don't know the definition of prescribed fire. There is clearly a need for program materials to emphasize the distinctions between wildfire and prescribed fire.

More residents are unconcerned (45%) or moderately concerned (27%) about the 1998 wildfires than are very concerned (28%), despite the barrage of news coverage. They believe the greatest benefit of prescribed fire is to prevent wildfires, and maintaining natural landscapes is the least important benefit of the four choices we provided. Respondents believe that prescribed fire involves large risks to wildlife and of the fire spreading to nearby land. Risks of car accidents, health concerns, and more regulations are perceived to be less important, though they exist. Thus, how wildlife responds to fire should be clarified and home landscaping measures could be introduced as a way to protect property from the risk of any kind of fire.

The Role of Experience

Experience is a powerful learning opportunity. Many educators strive to engage learners in an experience in order to make information more memorable. Consequently, effective communicators try to share information about experiences in messages in case the reality is not widely available or worth duplicating (e.g., war, famine, global warming). In the case of prescribed burning, a recent masters thesis indicated that locally held burns, accompanied with educational materials can positively influence knowledge and attitude (Heuberger, 1998). Our data set enabled us to ask if the experience of being near wildfire made a significant difference in the knowledge or attitudes of the respondents.

To make more generalizable statements about the power of experience, we created four scales of independent variables. The Knowledge Scale collapsed the true/false questions on fire, the definition of prescribed fire, and two ranking questions about the impact of wildfire and prescribed fire. The Air Quality Scale combined four attitudinal questions about air quality and smoke. The Natural Role of Fire Scale collapsed five attitudinal items covering natural ecosystems, forests, wildlife habitat, and fire. The Intention Scale combined the "likely" and "unlikely" responses to four questions about fire protection activities.

On these four scales, there were no significant differences between the 373 respondents from counties with more than 10,000 acres burned and the 290 respondents from counties that had less fire. In closer examination, it appears that Florida's counties are large enough to have people who lived near a wildfire (53% in high fire counties; 36% in low fire counties) and people who didn't (47% in high fire counties; 64% in low fire counties). Although county geography does make a significant difference regarding nearness to fire ($p<.01$), it evidently isn't enough to affect knowledge, attitudes, and intention.

The survey gathered data on a variety of other variables that establish experience with wildland fire: a burned nearby natural area, personal experience with prescribed fire, smoke at home during the 1998 fires, evacuation during 1998 fires, and natural resource or agriculture profession. Indeed, those respondents with some of these experiences were more likely to know more about fire and hold pro-fire attitudes than those without experience (see Table 6).

Table 6. Significant correlations (Kendall tau) at $p < .05$ between Fire Experience and Knowledge, Attitude, and Intention Scales (n=662)

Fire Experience	Knowledge Scale	Air Quality Attitude Scale	Natural Role of Fire Attitude Scale	Intention Scale
Nearby natural area burned	.07	.09	.10	
Defined prescribed burning	---	.17	.18	-.10
Personal experience with prescribed burning	.08	.12	.20	
Wildfire near residence	.13			-.07
Smoke at residence	.16	.14	.10	
Evacuated from residence		.08		-.09
Level of concern		.07		
Nat resource/ag employment	.09	.09	.12	-.05

Although these are experience variables are not tremendously strong predictors of knowledge, attitude, or intention, they do point to a relationship that may be worth cultivating. It is interesting that all experiences are not equally effective. Smoke, perhaps because it can be a gentle reminder without generating great fear, may be an effective proxy for direct experience in strengthening memory and interest in learning more. The only experience variable that generated a significant correlation with each of the scales is natural resource or agriculture employment. Certainly this variable combines years of interests, coursework, and experience that would be difficult to duplicate in the general population. All of the significant correlations with intention are negative: the more experience people have with fire, the less likely they say they are to take these four actions to protect their home. This may be because they have already taken these precautions, because less-informed fear contributes to the desire to take such actions, or because experience builds a fearlessness about the risks of fire.

Building Experience into Extension Programs

Because experiences with fire can affect knowledge and attitude toward wildland fire, our program will include experience substitutes. Demonstration areas, typically used in agricultural extension projects to teach skills and diffuse innovations, will be created to show the effects of a prescribed burn. Roadside signs will be erected where prescribed burns are visible from the road to remind people over time that the area was burned. Fears about whether the forest will recover could be mitigated by these gentle reminders. Similarly, the program will include press releases to announce an appropriate prescribed burns so the local media can cover the event. More information in the local news should be helpful in reminding people of the benefits and techniques of mimicking frequent low-intensity natural fires.

There is no doubt that Florida will experience more wildland fire. With helpful information and good communication, people should be able to react appropriately and experience minimal loss.

Literature Cited

Heuberger, Kimberly. 1998. Fire in the suburbs: Ecological, social and legal implications of prescribed fire in remnant longleaf pine sandhill. Unpublished masters thesis, University of Florida.

Public Attitudes and Knowledge about Ecosystem Management on Department of Defense Land in Florida

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Abstract: *New ecosystem management policies at Eglin Air Force Base, Florida, emphasize the need for public education and involvement in the changing focus of natural resource practices. To collect baseline information for ecosystem management, we measured and compared the knowledge, attitudes, and interests of critical Eglin audiences: recreational users and neighboring citizens. Factor analysis of surveys of 700 permitted recreational users and 1000 neighboring citizens revealed four content areas for measuring knowledge and attitudes: (1) native and endangered species, (2) fire ecology, (3) forest resources, and (4) ecosystem management. Overall, both audiences lacked basic ecological knowledge and held neutral to slightly positive attitudes toward the key content areas. Recreational users were significantly more knowledgeable than general citizens about native and endangered species, fire ecology, and forests. However, citizens held significantly more positive attitudes toward native and endangered species conservation and ecosystem management concepts. Eglin's consumptive recreationists (hunters and anglers) held the most negative views. Sociodemographic information from the surveys suggest that the recreational users and neighboring citizens are a stable, educable population that would respond positively to programs aimed at improving knowledge of and attitudes toward ecosystem management goals at Eglin.*

Actidudes Públicas y Conocimiento del Manejo de Ecosistemas de las Tierras del Departamento de Defensa en Florida

Resumen: *Las nuevas políticas de manejo de ecosistemas en la Base Eglin de la Fuerza Area en Florida, hacen énfasis en la necesidad de educación al público y su involucramiento en el cambio de enfoque de las prácticas de manejo de recursos naturales. Para colectar información base para manejo de ecosistemas, se midió y comparó el conocimiento, actitudes e intereses de audiencias críticas de Eglin: usuarios recreacionales y vecinos. Análisis de factores de encuestas a 700 usuarios con permiso y 1000 veccinos revelan cuatro áres para medir el conocimiento y las actitudes: (1) especies nativas y en peligro de extinción, (2) ecologia de incendios, (3) recursos forestales y (4) manejo de ecosistemas. En general, ambos grupos carecieron de conocimientos ecológicos básicos y mantener una actitud neutral o ligeramente positiva cor respecto a las áreas clave. Los usuarios de áreas de recreo tuvieron ligeramente un poco mas de conocimiento que los vecinos en lo que respecta a especies nativas y amenazadas, ecología de incendios y bosques. Sin embargo, los vecinos mantuvieron actitudes mas positivas con respecto a la conservación de especies nativas y amenazadas y hacia los conceptos ole manebo de ecosistemas. Los usuarios recreacionales de Eglin (cazadores y pescadores) mantienen las opiniones mas negativas. Informacion sociodemográfica de las encuestas sugiere que los usuarios y vecinos son una población estable y educable, que respondería positivamente a programas que pretendan mejorar el conocimiento de y actitudes hacia metas de manejo de ecosistemas en Eglin.*

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Introduction

The growing ecosystem management movement on public lands in the United States requires the effective incorporation of people into management plans. Ecosystem management has been defined as the synthesis of "scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term" (Grumbine 1994). Many researchers increasingly recognize the importance of humans as central components of ecosystem management and the role of human values in guiding natural resource policies. These themes are referred to in 85% of recent ecosystem management reports (Grumbine 1994). Land managers must better understand the attitudes and awareness of their public constituencies.

High levels of public involvement are characteristic of ecosystem management schemes, which generally seek to integrate planning, decision-making, research, public involvement, and management into a comprehensive system (Slocombe 1993; Hardesty 1994). Ecosystem management is a departure from traditional expectations in that it does not focus on a particular species, but on entire systems; thus, the need for public input and education concerning the adoption of this new and different management approach. Natural resource managers and planners must be able to establish a common understanding among people with different knowledge levels, attitudes, and values and build agreement among diverse groups of people (Grumbine 1994). They must develop a better understanding of local and regional cultures and peoples and their bearing on the natural environment. This social data can then be integrated with ecological information to enhance management efforts.

Recent polls show high levels of public support for concepts of environmental protection and wildlife conservation. For example, a Times Mirror Magazines (1994) poll found that 60% of U.S. citizens felt that environmental protection was more important than economic development when compromise could not be found. The National Opinion Research Center (1995) showed that 61% of respondents recognized that humans were the main cause of species extinctions. In a similar poll, ABC News/*Washington Post* (1995) found that 70% of the public thought that the government had not gone far enough in protecting the environment.

Although these polls show that the public holds supportive attitudes and has some awareness of environmental problems, researchers have found that the views toward the environment of most U.S. citizens are based on limited ecological understanding and that concern for wildlife is largely confined to attractive and emotionally appealing species (e.g., Kellert 1980*a*). Gigliotti (1990) bemoans "a citizenry that is emotionally charged but woefully lacking in basic ecological knowledge." If ecosystem management is to thrive, innovative education efforts must build on existing positive attitudes to expand the public's narrow focus and improve ecological understanding as the basis for informed decisions.

Where traditional land managers considered education superfluous, some managers are now beginning to test and accept the use of education as a tool to meet specific natural resource goals (e.g., Jacobson 1995*a*). Public education can increase public support, improve behavior, reduce vandalism, decrease poaching, increase effective carrying capacities, and influence policies and decisions that affect public lands (Cable & Knudson 1983; Jacobson 1990).

Knowledge of social variables is particularly important when agencies are expanding into new program or management areas. For example, a shift toward ecosystem management at Eglin Air Force Base in Florida, home to the largest longleaf pine forest left in the Southeast, will bring about changes in field practices that will affect recreational users and neighboring citizens. Restoration of fire-dependent pine ecosystems will entail increased prescribed burning and more growing season burns. Although prescribed burning can accomplish management objectives, smoke and temporarily degraded landscapes can engender negative attitudes where the public lacks understanding of the benefits of fire.

Concomitant with the changing management focus, Eglin faces increased public demand for recreational opportunities. One way to balance additional recreational demand with resource conservation is through knowledge of users and the modification of recreational behaviors to meet management goals (Duffus & Dearden 1990). The incorporation of social values into management objectives is essential for successful management programs and long term protection of natural resources. Wildlife managers can use social indicators to formulate management objectives, develop effective—often educational—solutions to management problems, and select socially and politically acceptable actions (Decker 1990). People affect public lands not only by direct use, but also by influencing management and land-use policies. Stronger public support for ecosystem management policies can result from the effective use of social science data.

As a prerequisite to developing a public education program for ecosystem management of the 185,600-ha Eglin Air Force Base, this study was conducted to identify and better understand the recreational users and neighboring citizens of Eglin. Results will be used to develop effective methods of communication about the principles of ecosystem management for these audiences. Eglin's ecological significance, diverse recreational groups, and surrounding population of over a half million people make it ideally suited to measuring regional public knowledge and attitudes toward ecosystem management.

The study was based on a systematic model for pro-

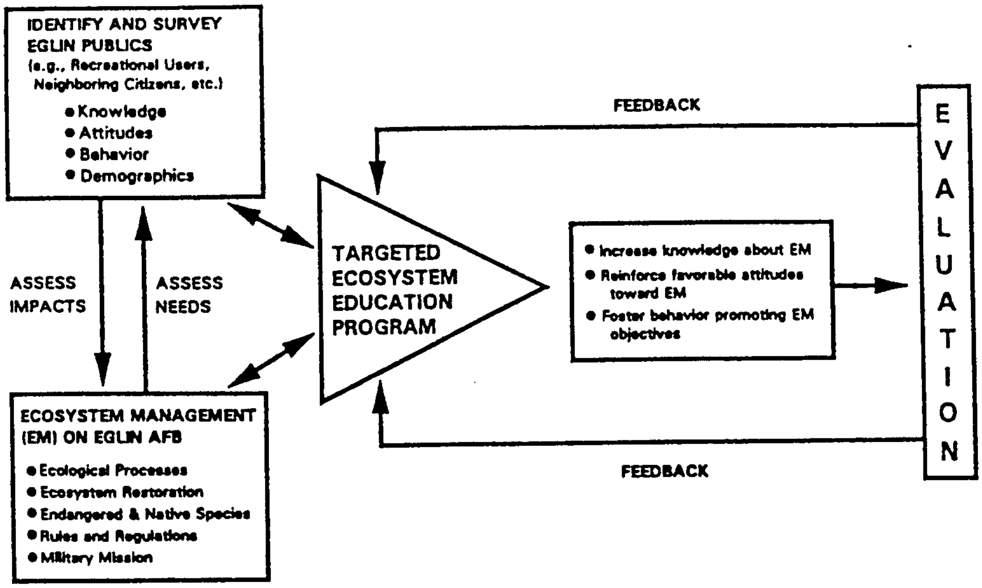


Figure 1. Model for integrating public survey data with ecosystem management (EM) needs to develop a targeted public education program at Eglin Air Force Base.

gram evaluation (Jacobson 1991, 1990). As adapted for Eglin Air Force Base, the approach focuses on the merging of baseline survey data with biological management needs. From this, an educational program can be formulated to reach target audiences at the appropriate level to accomplish management goals (Fig. 1). We report here on the results of Eglin's public surveys. Subsequent to the implementation of an educational program based upon the knowledge and attitude levels of the target audiences, the survey can be administered again to evaluate, monitor, and modify the program.

Methods for assessing attitudes and behaviors include interviews, written and oral surveys, participatory workshops, public meetings, document analysis, and other qualitative and quantitative data collection techniques (Jacobson 1995*b*). Because of the size and geographic range of the populations being studied, a self-administered mail questionnaire was selected for data collection. Mail surveys are advantageous because they promote honesty through confidentiality, eliminate interviewer bias, permit wide geographic and target population coverage, and are inexpensive and convenient compared to phone surveys or personal interviews (Dillman 1983; Miller & Miller 1991).

This study explores the knowledge, attitudes, and activities of both recreational users and local citizens toward the changing focus of land management on Eglin Air Force Base. Social surveys can guide management decisions, as well as provide baseline data to assess the efficacy of new programs and policies. Results of the surveys will provide a backbone around which Base administration can design management policies that better incorporate human populations into long-term strategies for managing the Base and into short-term public education initiatives. Effective approaches to land management involving the public on Eglin can serve as a model for the Department of Defense—the fifth largest land manager in the federal government—and other public land agencies.

Methods

Study Site

Eglin represents 78% of U.S. Air Force (USAF) lands and is the largest forested military installation in the western hemisphere. Eighty-six percent of Eglin is forested, and 26 of Florida's 66 natural community types have been identified on Eglin (USAF 1993). Eglin's longleaf pine forests have been identified as a critically endangered ecosystem type in the U.S. (Noss et al. 1995). Wildlife inhabiting the Base include 22 animal species and 67 plant species that are rare, of special concern, threatened, or endangered (USAF 1993).

Approximately 29,000 personnel and family members reside on the Base. An urban and rural population of over half a million live in the four counties surrounding Eglin. Nearly 110,000 ha of Eglin are open for permitted public recreational use, providing opportunities for hunting, fishing, camping, hiking, canoeing, bicycling, and wildlife observation. In 1992 the Natural Resources Division issued approximately 6400 permits for hunting, 3300 for fishing, and 4600 for general recreation and camping on Eglin. The Natural Resources Division at Eglin is responsible for supporting the military mission through sound stewardship of natural resources and for assuring the availability of the resources of the Base to future generations.

The Natural Resources Division created a 5-year strategic Natural Resources Management Plan (NRMP) in 1993 with input through public meetings and scientific workshops. The NRMP replaces the commodity-oriented

nagement of the past with an adaptive approach to nagement of the whole Eglin landscape, providing :liminary strategies for data collection, monitoring, .intenance, and restoration of viable ecosystems and :ural biological diversity. In particular, the plan fo- ses on restoration of longleaf pine sandhill ecosys- ns, which will benefit populations of many threat- ed and endangered species, such as the Red-cockaded oodpecker (*Picoides borealis*). In the plan public edu- tion and public recreation are identified as two of ʒht major management issues for Eglin. Before this ɹdy no educational research had been conducted or ˌseline data collected about Eglin's publics.

ɪrvey Design and Implementation

ɾoss sectional surveys of Eglin recreational user and cit- en populations were conducted. A random sample of)0 recreational users was selected from the population f people purchasing Eglin recreational permits in fiscal 992. A sample of 1000 citizens was selected from the :ea population of adult heads-of-households in Escam- ia, Santa Rosa, Okaloosa, and Walton counties within a 0-mile radius of Eglin. The user and citizen surveys ,ere designed according to standard survey research ıethodology (Dillman 1983; Borg & Gall 1989; Miller & liller 1991) and modeled after similar survey evalua- ions of conservation education programs (Jacobson 1988). An iterative design process was used to decide on content, draft questions, and order and format of questionnaire, to pretest the instrument, and to revise the draft and design stages as necessary (Sheatsley 1983).

Survey objectives and content areas were defined through a combination of interviews with Eglin natural resources personnel, review of the NRMP, and consultation with area citizens and outside natural and social scientists. The surveys focused on four content areas: ecosystem management, endangered species, the ecological role of fire, and forest resources used by humans and wildlife. As recommended by other researchers working with natural area constituents, the instrument was designed to measure public awareness of and support for the natural resources, management policies, and recreational opportunities of the Base (Motts 1983; Hammitt 1984).

Attitude questions were designed around a symmetric 5-point scale (1 = strongly disagree to 5 = strongly agree), with clear and separate alternatives and a central neutral category (Borg & Gall 1989). Knowledge questions were designed to measure familiarity or awareness using a true-false format (McDonough & Lee 1990). The surveys were subjected to expert scientific review and pilot tested among members of the selected populations (n = 20) to insure validity and clarity (Fink & Kosecoff 1985). The final baseline surveys for citizens and recreational users consisted of four core sections: 18 attitude questions; 12 knowledge questions; 15 questions about

'able 1. **Attitude composites from survey results of recreational users and neighboring citizens, based on a scale of increasing support rom 1 (strongly disagree) to 5 (strongly agree).**

Statements from survey	*Users*	*Citizens*
Eglin's endangered plant and animal populations should be increased.	3.65	3.68
Eglin managers should focus on conserving native plants and animals.	3.55	3.61
Some secondary roads on Eglin should be closed to improve native wildlife habitat.	2.92	3.32
Large native animals would benefit if Eglin were better connected to Blackwater State Forest.	3.20	3.42
Eglin is important in the southeast for native plants and animals.	3.88	3.82
Eglin managers should focus on conserving native pine forests.	2.61	2.73
More should be spent on management of endangered plants and animals at Eglin.	3.38	3.26
The number of people allowed to use Eglin should be limited.	2.85	3.57
Recreational impacts to Eglin's native plants and animals should be limited.	3.52	3.97
Native and endangered species attitude composite	3.30	3.48
Eglin should burn forests despite potential air pollution.	3.59	3.21
Fire is beneficial to Eglin's native trees and plants.	3.05	2.72
More areas of Eglin should be burned to increase wildlife habitat.	3.25	2.79
Fire ecology attitude composite	3.30	2.91
Wildlife prefer habitats that have some pine forests and some oak forests.	4.12	3.91
Enough timber is being harvested on Eglin.	3.72	3.38
Wildlife prefer forests with mixed tree species.	3.99	3.76
Eglin is important in the southeast for native plants and animals.	3.88	3.82
More money should be spent on management of endangered plants and animals at Eglin.	3.38	3.26
Mature pine forests are necessary for Eglin's wildlife.	4.08	3.99
Eglin's endangered plant and animal populations should be increased.	3.65	3.68
Forest resources attitude composite	3.86	3.69
Eglin managers should have a broader focus than game animals alone.	2.75	3.25
Eglin managers should focus on whole forest systems rather than specific species.	3.73	3.89
Recreational impacts to Eglin's native plants and animals should be limited.	3.52	3.97
Eglin managers should have a broader focus than the conservation of native pine forests alone.	3.39	3.27
Ecosystem management attitude composite	3.33	3.63

outdoor recreation behaviors and interests; and 12 sociodemographic questions. Natural Resources Division staff added extra questions specifically for Eglin's recreational users.

Survey implementation followed recommendations for maximizing response rates (Dillman 1983). Surveys were disseminated in three stages: (1) a survey package with a postage paid return envelope and a cover letter outlining the purpose of the research, (2) a second survey package with return envelope and new cover letter seeking cooperation, and (3) a reminder postcard. Form letters on official U.S. Air Force letterhead were used to encourage response. Mailings occurred at three-week intervals, with follow up mailings to people who had not yet responded to the survey, as tracked by code numbers printed on the back of each survey. Attitude composites are reported as mean levels of support on a scale of 1 = strongly disagree to 5 = strongly agree. Knowledge scores are reported as percent correct out of a possible 100%. Based on a factor analysis, composite scores are used to report results, compare user and citizen responses, and compare recreational and sociodemographic subgroups (Kim & Mueller 1978; Marradi 1981). Survey data analysis used standard statistical procedures (SAS Institute 1988); significance is reported at the $p \leq 0.05$ level.

Results

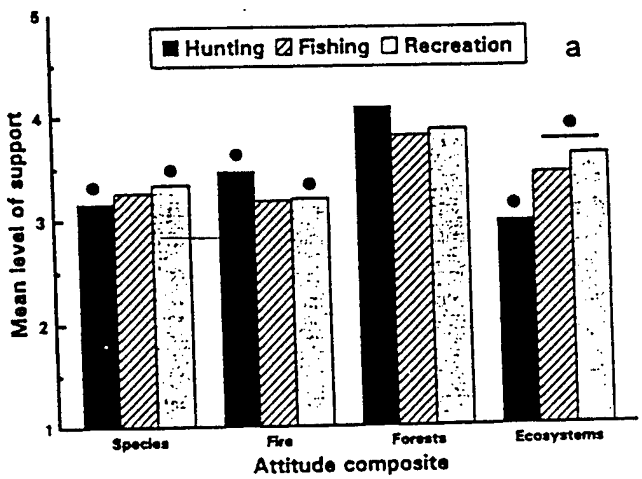
Response rates were 60% ($n = 370$) for the user survey and 45% ($n = 385$) for the citizen survey, with overall margins of error of 3.64% and 3.25%, respectively. Twelve percent of user surveys and 14% of citizen surveys were undeliverable. Factor analysis of survey results confirmed that questions could be categorized into four composite scores for analysis and interpretation. These dimensions represented: (1) native and endangered species; (2) fire ecology; (3) forest resources and habitats; and (4) ecosystem management.

Attitudes toward Native and Endangered Species

The *native and endangered species composite* encompasses nine attitude questions from the surveys (Table 1). Whereas participants in hunting, fishing, and recreation on Eglin were nearly neutral concerning native and endangered species management, Eglin's hunters exhibited less support (3.2), and respondents participating in general recreation showed significantly more support (3.3) for an increased focus on and investment in the conservation of native and endangered species ($F = 4.55$, $p = 0.01$) (Fig. 2a). Support for native and endangered species programs did not differ between groups of users based on education levels, income levels, or rural vs. urban residency. Nor did attitude differences exist on the native and endangered species composite among citizen groups based on recreational activity (Fig. 2b), income level, educational attainment, or place of residence.

Attitudes toward Fire and Forest Resources

The *fire ecology composite* includes three survey attitude questions (Table 1). Attitudes toward the role of fire in ecosystem restoration at Eglin were uniformly neutral across all groups, except between hunters and recreationists (Fig. 2a). Eglin's hunters expressed significantly more positive attitudes about fire (3.5) than the more neutral recreationists (3.2, $F = 3.91$, $p = 0.02$). Citizens rated a low level of support (2.9) on the fire composite. Although citizen attitudes did not differ on this composite according to recreational (Fig. 2b), educational, or urban/rural groupings, differences between



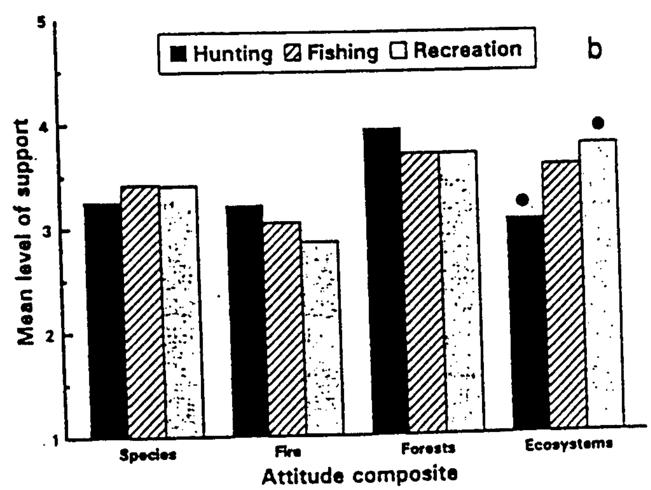


Figure 2. Attitude scores on a scale of 1 = strongly disagree to 5 = strongly agree by recreational activity of Eglin users (a) and neighboring citizens (b). Filled circles indicate significant differences at p *< 0.05, line over bars indicate that those two bars differ from the third in the group.*

come levels were significant. Families making less than 25,000/year displayed more negative attitudes toward re (2.4) than higher income groups (F = 21.66, p = .0001), who were neutral on the subject.

Seven attitude questions are included in the *forest resources composite* (Table 1). No attitude differences were recorded on this composite among users or citizens based on recreational activity (Fig. 2), income, education, or rural vs. urban residency; the average support was 3.9 for users and 3.7 for citizens.

Attitudes toward Ecosystem Management

The *ecosystem management composite* combines four attitude questions from the surveys (Table 1). Eglin user groups exhibited significant differences in support for ecosystem management at Eglin. Users participating in general recreation (3.6) and fishing (3.4) showed higher levels of support for a broader management focus than hunters (3.0, F = 17.69, p = 0.0001) (Fig. 2a). Users with more education showed significantly higher support for ecosystem management concepts than those with less education (F = 12.34, p = 0.0001). Users in higher income groups exhibited more support for an ecosystem focus for Eglin than those in lower income groups (F = 5.67, p = 0.004). Finally, users who were urban residents expressed more support for a broader focus (3.4) than rural residents (3.1, F = 6.73, p = 0.01).

Citizens who primarily engaged in general recreation were much more supportive of an ecosystem focus at Eglin (3.7) than citizens who were hunters (3.1, F = 7.29, p = 0.0008) (Fig. 2b). Citizens with higher education showed significantly greater support (3.7) for ecosystem management concepts than those with high school or less education (3.4, F = 4.19, p = 0.02). Those in higher income groups (≥\$25,000/year) exhibited more support for an ecosystem focus than citizens with lower income (F = 8.06, p = 0.0004). A similar trend was seen between citizens who were urban versus rural residents.

Knowledge of Native and Endangered Species

Eglin recreational users exhibited some basic knowledge about the common native plants and animals that inhabit the Base (Table 2). For example, many respondents correctly identified white-tailed deer (96%), alligator (92%), beaver (91%), bobcat (82%), red fox (81%), black bear (78%), coyote (76%), gray fox (72%), and otter (62%) as inhabitants of Eglin. Yet, only 33% of respondents knew that Bald Eagles occur on Eglin, and 40% of respondents mistakenly believed that panthers still occur on Eglin. Furthermore, only one-third (33%) of user respondents knew that the longleaf pine is the most widespread tree on Eglin. Citizen respondents exhibited less knowledge about Eglin's species (e.g., only 15% of citizen respondents knew the prominence of Eglin's most widespread tree, the longleaf pine).

Although 51% of recreational users understood that thinning of pine forests could be beneficial to Eglin's endangered species, less than half could identify Eglin's most well-known endangered species, such as black bear

Table 2. **Knowledge composites and total knowledge scores of recreational users and neighboring citizens based on percent correct out of 100%.**

Abbreviated statements from survey	*Users*	*Citizens*
The most widespread native tree on Eglin is the longleaf pine.	32.7	14.9
Thinning of pine forests can benefit endangered plants and animals.	51.4	46.0
The following animals live on Eglin: alligator, Bald Eagle, beaver, black bear, bobcat, coyote, gray fox, otter, Pileated Woodpecker, red fox, white-tailed deer (11 parts).	73.7	50.3
The following animals are threatened or endangered: alligator snapping turtle, Bald Eagle, black bear, indigo snake, fox squirrel, gopher frog, gopher tortoise, green sea turtle, loggerhead sea turtle, Okaloosa darter, Red-cockaded Woodpecker (11 parts).	29.8	21.1
Eglin's endangered woodpeckers nest in live pine trees.	36.5	23.8
Eglin's endangered woodpeckers nest in trees over 80 years old.	30.0	23.0
Native and endangered species knowledge score	50.0	34.4
Fire benefits Eglin's native plants.	55.7	38.1
Regular fire maintains a balance of pine and oak trees.	37.0	31.3
Regular fire is a characteristic of mature (old-growth) pine forests.	11.9	10.9
Pine forests that are burned every few years are useful to wildlife.	62.7	48.0
Fire ecology knowledge score	41.8	32.0
Mature (old-growth) pine forests are characterized by: snags and logs, many nuts and berries, large pine trees, regular fire, abundant wildlife, little underbrush, thick grasses (7 parts).	33.0	26.3
Forest resources knowledge score	33.0	26.3
Eglin's forests are resting places for birds that migrate between North America and the tropics.	59.2	63.4
Forests along streams and rivers are necessary for traveling wildlife.	83.2	77.0
Ecosystem management knowledge score	71.2	69.9
Total knowledge score	49.0	36.1

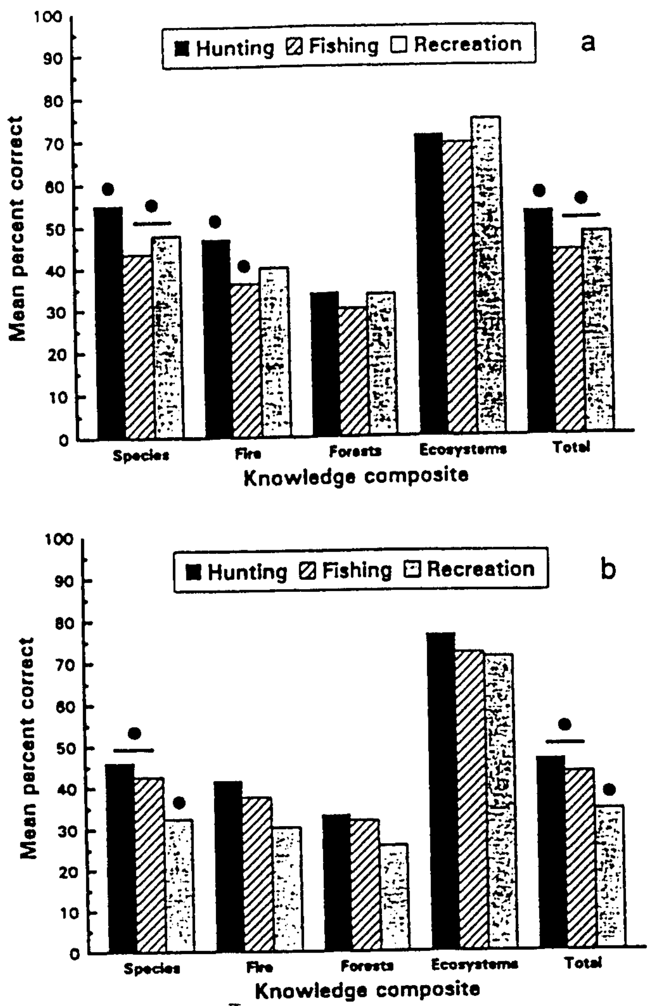


Figure 3. Knowledge scores by recreational activity of Eglin users (a) and neighboring citizens (b). Filled circles indicate significant differences at p < 0.05, *line over bars indicate that those two bars differ from the third in the group.*

(46%), Bald Eagle (46%), gopher tortoise (42%), and fox squirrel (41%). Only one-third of the users recognized Eglin's endangered Red-cockaded Woodpecker (32%), and even fewer respondents identified Eglin's less charismatic endangered species, such as the loggerhead sea turtle (26%), green sea turtle (26%), alligator snapping turtle (22%), Okaloosa darter (20%), indigo snake (19%), and gopher frog (6%). The endangered animals most recognized by citizen respondents were the Bald Eagle (45%) and black bear (29%). Few citizens recognized the Okaloosa darter (12%), indigo snake (7%), or gopher frog (4%) as endangered species, whereas 15% incorrectly said that the Great Blue Heron was endangered.

A lack of knowledge about the native and endangered species of Eglin extended to ignorance of the natural history of those species. Only 36% of the users and 24% of the citizens surveyed knew that Eglin's Red-cockaded Woodpeckers nest in live pine trees, and 30% of both users and citizens knew that the woodpeckers nest in mature trees. Among Eglin recreational users, hunters scored significantly higher on the species knowledge composite (55%) than anglers (44%) or general recreationists (48%, $F = 11.03, p = 0.0001$) (Fig. 3a), and rural residents scored significantly higher (55%) than urbanites (49%, $F = 4.22$, $p = 0.04$). Citizens who participated in general recreation were significantly less knowledgeable (32%) than citizens who fished (43%) or hunted (46%, $F = 8.36, p = 0.0003$) (Fig. 3b), and male citizens scored significantly higher (37%) than females (27%, $F = 19.52$, $p = 0.0001$). Significant differences also were seen based on family income: citizens with lower incomes were significantly less knowledgeable (<\$25,000/year: 28%) than citizens with higher incomes (≥\$25,000/year: 37%). There were no significant differences in citizen scores based on educational attainment or residency.

Knowledge of Fire Ecology

Respondents revealed a lack of awareness of the importance of fire to the ecosystems and species of Eglin (Table 2). Eglin users were most knowledgeable about the general benefits of fire to wildlife populations, with 63% agreeing that areas that are burned every few years would be useful to wildlife. Fewer users (56%) knew that fire was beneficial to Eglin's native plants; 37% knew that regular fire could help maintain the balance of pine and oak trees in Eglin's forests. Furthermore, users had a profound lack of knowledge of the role of fire as a structuring element in the mature pine forests seen on Eglin. Only 12% of respondents identified "regular fire" as a component of Eglin's mature pine forests.

Citizen respondents were moderately knowledgeable about the general benefits of fire to wildlife habitat, with half (48%) agreeing that areas that are burned every few years could still be useful to wildlife. Fewer citizens (38%) knew that fire benefitted Eglin's native plants, and less than one-third (31%) that regular fire could help to maintain the balance of pine and oak trees in Eglin's forests. Only 11% of citizen respondents identified "regular fire" as a component of Eglin's mature pine forests.

Recreational activities of respondents influenced their knowledge of fire ecology (Fig. 3). Among Eglin's users, hunters (47%) were significantly more knowledgeable than anglers (36%) about the benefits of fire for native vegetation ($F = 3.67, p = 0.03$). Among citizen respondents, men were significantly more knowledgeable (36%) about fire's benefits than women (21%, $F = 16.20$, $p = 0.0001$), and citizens with higher incomes (\$25,000–\$49,999/year: 33%, ≥\$50,000/year: 40%) were more knowledgeable than lower income citizens (<\$25,000/year: 22%, $F = 9.06, p = 0.0001$).

owledge of Forest Resources and Ecosystem Management

summary *forest resources knowledge score* on the mponents of mature pine forest habitats yielded low erall scores of 33% for recreational users and 26% for izen respondents (Table 2). On individual questions, ers were unfamiliar with some basic elements of mare pine forests on Eglin. Whereas 73% knew that ırge pine trees" are a component of mature pine forts, only a moderate number identified "snags and logs" 8%) and "little underbrush" (37%) as components, and ·ry few named other key components, such as "thick asses" (19%) and "regular fire" (12%). Citizens also ere unfamiliar with the basic elements of mature pine rests on Eglin: while 60% knew that "large pine trees" ere a component of mature pine forests, 40% identied "snags and logs" (40%), and few identified other key omponents, such as "little underbrush" (24%), "abunınt game" (24%), "nuts and berries" (14%), "thick asses" (10%), and "regular fire" (11%). Scores did not iffer based on sociodemographic characteristics, exept for respondent gender. Male citizens were more nowledgeable (28%) than females (21%, $F = 7.77$, $p =$ .006) about forests.

On questions included in the *ecosystem management nowledge score* (Table 2), 59% of users thought Eglin as a good resting place for birds that migrate between orth America and the tropics, and 83% recognized that orests along streams and rivers were important for wildfe habitat and movement. Among citizens, 63% thought glin a good resting place for migrating birds, and 77% ecognized that forests along streams and rivers were mportant for wildlife habitat and movement. On a summary of these ecosystem knowledge questions, users verall averaged 71% correct and citizens averaged 70%. o significant differences were found based on user or itizen demographic characteristics.

otal Knowledge Scores

mong Eglin's users hunters were significantly more nowledgeable about Eglin's natural resources (53%) han people involved in fishing (44%) or recreation 48%, $F = 8.03$, $p = 0.0004$) (Fig. 3a). Rural residents also were more knowledgeable (53%), than urban residents (48%, $F = 4.31$, $p = 0.04$). Citizens who hunted (47%) or fished (44%) were more knowledgeable about Eglin's natural resources than citizens who were involved in general recreation (35%, $F = 8.11$, $p = 0.0004$) (Fig. 3b). Male citizens were more knowledgeable (39%) than females (29%, $F = 20.16$, $p = 0.0001$), and citizens with higher family incomes (≥$25,000/year: 39%) were more knowledgeable than low-income citizens (<$25,000/year: 30%, $F = 7.66$, $p = 0.0006$). No differences in total knowledge were seen on the basis of citizen educational attainment or residency.

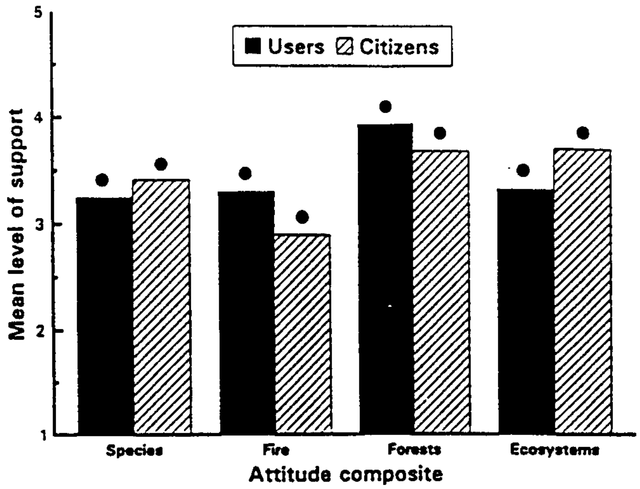


Figure 4. Attitude scores of Eglin users versus neighboring citizens. Filled circles indicate significant differences at $p < 0.05$.

Comparison of Users and Citizens

Overall, users and citizens held primarily neutral to slightly positive views toward issues of native and endangered species, fire ecology, forest resources, and ecosystem management (Fig. 4). Eglin users expressed slightly positive attitudes toward the role of fire in Eglin's forests (3.3), whereas citizens had lower and slightly negative attitudes about fire (2.9, $t = 6.06$, $p = 0.0001$). Users also had more positive attitudes of forests (3.9) than citizens (3.7, $t = 6.44$, $p = 0.0001$). Conversely, citizens expressed more support (3.4) for protection of native and endangered species than users (3.2, $t = 4.02$, $p = 0.0001$), and citizens were more positive (3.7) about ecosystem management issues than users (3.3, $t = 6.55$, $p = 0.0001$).

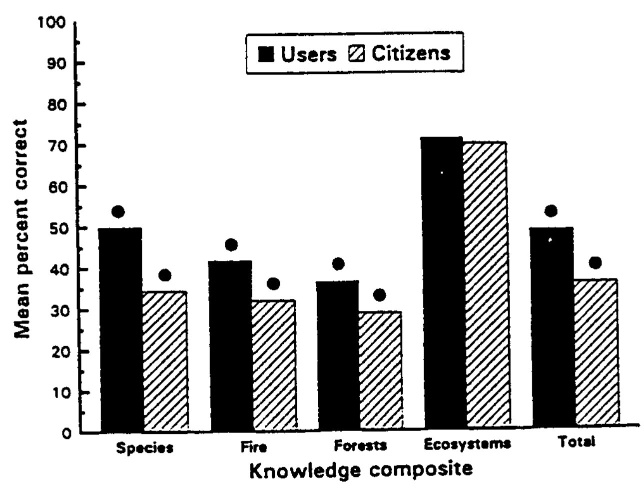


Figure 5. Knowledge scores of Eglin users versus neighboring citizens. Filled circles indicate significant differences at $p < 0.05$.

As measured by composite and total knowledge scores, citizens and users differed on average knowledge levels (Fig. 5). Respondents to the user survey knew more about forests (37%) than did area citizens (29%, $t = 4.34$, $p = 0.0001$) and were more knowledgeable about fire (42%) than citizen respondents (32%, $t = 4.42$, $p = 0.0001$). Despite their more negative attitudes about native and endangered species, users scored better on knowledge questions related to native and endangered species (50%) than citizens (34%, $t = 10.63$, $p = 0.0001$). Knowledge levels on the ecosystem composite were comparable for user and citizen respondents, with nearly three-quarters of respondents recognizing the importance of diverse forest ecosystems at Eglin and the role of Eglin's ecosystems in the regional landscape. Overall, recreational users (49%) were more knowledgeable than citizens (36%, $t = 9.73$, $p = 0.0001$) about ecosystem management and natural resource topics at Eglin.

Respondent Demographics

The sociodemographic data from the surveys indicated that the user and citizen respondents represent similar demographic groups. User respondents were slightly more educated and had higher incomes than the general population, and respondents to the citizen survey also were better educated and fell more often into middle and upper income brackets than the general population (Bureau of Economic and Business Research 1992). Because surveys were sent to Eglin users and area heads-of-households, a majority of respondents to both surveys were male (74–86%) and both groups were older (43–51) than the median age for Escambia, Okaloosa, Santa Rosa, and Walton counties (32–38). Respondents were overwhelmingly Caucasian (91–95%), not surprising in a four-county area with a 77–94% Caucasian population. Both sets of respondents had lived in the area an average of 12 years, and over three-quarters of both groups intended to stay for at least 10 more years.

Discussion

The survey results clearly depict the existing knowledge and attitude levels of recreational users and neighboring citizens toward key areas of ecosystem management on Eglin Air Force Base. Specifically, Eglin permit holders lack knowledge about local native and endangered species, forest resources and habitats, and the function of disturbances such as fire in Eglin's ecosystems. Citizens of surrounding communities are even less knowledgeable than Eglin's permitted users. However, Eglin users and area citizens have a basic grasp of some broader ecosystem concepts and show neutral to slightly positive attitudes toward all of the key management concepts.

On the whole, both users and local citizens expressed their highest levels of support for forest resources, which included a range of issues that held broad appeal and were more easily understood by users and the general public. Of note, Eglin users held more supportive attitudes toward issues with which they had direct experience, such as forests and the use of fire for resource management, whereas area citizens expressed more support for ecosystem management and protection of native and endangered species, concepts that may have broad appeal as environmental issues for the general public but may be perceived by recreational users as untested theories or threats to continued enjoyment of forest recreation. Among recreational categories, hunters were least supportive of endangered species protection. Likewise, concepts of ecosystem management appealed more to those who were highly educated, urban, affluent, and/or participating in low consumption recreation, rather than those who were less well educated, less affluent, rural, and/or involved in consumptive recreational activities. This pattern of support may reflect the novelty and abstract nature of the ecosystem management concept, which may not yet have been satisfactorily explained or proven beneficial to consumptive recreational users. Sociodemographic characteristics such as lower income and educational levels correlated with less support for ecosystem management objectives. Kellert (1980*a*) and others have found these groups generally hold more negative views toward the environment.

Knowledge scores of citizens and users differed in all content areas. Users were more knowledgeable about forests and fire ecology than citizens. Despite their more negative attitudes about native and endangered species, users also scored higher than citizens on knowledge questions related to native and endangered species. This probably reflects users' higher level of direct exposure to species and systems at Eglin and emphasizes the complex and often indirect relationship between knowledge and attitudes (Hungerford & Volk 1990).

All respondents revealed relatively low levels of knowledge about forest resources and fire ecology and surprisingly high knowledge levels regarding ecosystem issues, with about 70% of respondents recognizing the importance of diverse forest ecosystems at Eglin and the role of Eglin's ecosystems in the regional landscape. The high ecosystem knowledge scores represented general awareness at a conceptual level that was not backed up by basic ecological knowledge of the components, structures, and functions of Eglin's forest ecosystems.

The sociodemographic data from the user and citizen surveys reveal stable, well-educated, middle class populations of users and local citizens, with long tenure in the area and an interest in natural resource issues. These groups make good target audiences for an education program on ecosystem management. They also could provide community leadership toward greater citizen

rticipation in the future protection and enhancement Eglin's natural resources.

In recent years public recreational lands have abrbed major increases in wildlife-related outdoor activi:s. Traditional recreational groups such as hunters and glers are part of this groundswell of public interest, t national and state recreational data show increases in ildlife viewing and other low consumption recreation the last two decades (U.S. Fish & Wildlife Service)89, 1988, 1982). With mainstream public interest ıifting toward low consumption uses, managers and)licy makers must examine the common interests nong traditional consumptive recreationists and the :w low consumption constituency. For example, in a ew York survey, hunters consistently held nongame ılues of wildlife in higher regard than traditional huntg values. Hunters' highest ideals were "to get outdoors ıd enjoy nature" and "to see deer or deer signs," 'hereas shooting at deer and using hunting skills were :condary values (Decker 1990). Like hunters, low conımption recreationists enjoy the chance to get outoors and observe or feed almost any type of wildlife in most any type of habitat. Traditional game species, parcularly deer, waterfowl, and small mammals, are imortant in providing these wildlife observation opportuities (Shaw & Mangun 1984). Jackson (1982) found ıat people interested in and supportive of nongame nd endangered wildlife may be hunters and anglers, as :ell as birdwatchers, hikers, and paddlers.

Witter and Shaw (1979) report that consumptive and)w consumption recreationists have some of the same ıotivations and interests, enjoy seeing many of the ame wildlife species, concur on the ways in which vildlife are valuable, and agree on the importance of ıabitat conservation. Yet our data reveal significantly :fferent attitudes among consumptive and general rec:ationists, with implications for the content of public ıformation programs targeting these groups. Even nong subgroups of consumptive users, different attiıdes were present. For example, among Eglin hunters, alk hunters expressed significantly higher levels of ɹpport for native and endangered species conservation han did dog hunters ($F = 14.86$, $p = 0.0002$). Eglin's :onsumptive recreationists (hunters and anglers) held he most negative views. This lack of support may relect a perception that native and endangered species :onservation programs compete with, detract from, or nterfere with hunting or fishing programs.

Understanding the differences as well as the similari:ies among recreational users will improve ecosystem management capabilities. Growing demand for low consumption outdoor recreation will necessitate a shifting focus toward serving more general recreational needs ınd will require more intensive management interven:ions to maintain recreational opportunities without permanent harm to finite natural resources. Recreational users of public natural resources are an audience ripe for education programs. Duda (1987) found that while recreational users already were more supportive of natural resource management processes than average Floridians, they also were more likely to want additional information. Ecosystem management goals may focus on biological problems, but future management actions must involve conservation education programs. These will use sociodemographic data to design targeted materials to address people's knowledge, attitudes, and behaviors toward the biological resources and their management.

Conservation education as a recreational and management activity has not been a traditional part of the U.S. Department of Defense objectives or actions as it has on many other public parks and forests across the U.S. (Adams & Hammitt 1995). Yet the public is supportive of government involvement in natural resource education programs (Dunlap et al. 1993; Kellert 1980*b*). Defense Department policies toward natural resource management are changing as the military realizes that land is a finite resource that must be protected in order to allow continued use for training and testing, as well as for future generations (Siehl 1991). Preliminary signs of change can be seen in the Army's Integrated Training Area Management program, which calls for troop education and environmental damage control before training missions, and the Department of Defense's Legacy Resource Management Program, which supports natural resource education, research, and management projects.

The importance of education is apparent as more and more environmental policy decisions are made with extensive public input. Environmentally knowledgeable and responsible natural resource users are of paramount importance in developing heightened public support for ecosystem management plans and policies. Before this research, awareness, attitudes, and interests of Eglin user groups and citizen neighbors were not known. For Eglin's ecosystem management plan to succeed, appropriate and effective communications must reach the recreational users of Eglin's natural resources and the public who may influence future policy direction. Management program visibility and motivated recreational audiences make public education a good prospect for stimulating broad based support for Eglin's ecosystem management program.

The survey results provide a scientific foundation to develop and improve communications about ecosystem management for constituencies who are likely to act toward the conscientious stewardship of Eglin's natural resources. By understanding the knowledge, attitudes, behaviors, and sociodemographic backgrounds of the users and neighbors of Eglin, effective methods of public communication can be developed. The content and approaches of an ecosystem education program for various publics of Eglin Air Force Base can be designed to satisfy identified deficits in public knowledge and atti-

tudes and geared toward increasing awareness and support for ecosystem management topics in the content areas explored. Educational materials can include information about principles of ecosystem management, communities and species present on the Base, the role of disturbances such as fire in ecosystem functioning and restoration, human uses and behaviors compatible with Eglin's ecosystems, and information to facilitate outdoor recreation and wildlife observation. Educational materials also can seek to enhance the neutral to positive attitudes toward the biological resources of Eglin displayed by survey respondents. Based on survey results, rationales for ecosystem management and conservation can incorporate ecological, economic, moral, and aesthetic arguments specifically targeted to subgroups of the population.

Over the long term, this study will assist natural resource managers in determining the effect of conservation education efforts in meeting overall ecosystem management goals through enhanced communication, better recreational management, timely monitoring, and a better understanding of mechanisms for increasing public involvement.

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Literature Cited

ABC News/Washington Post. 1995. ABC News/Washington Post poll, May 11-14, 1995. ABC News, New York.

Adams, A., and W. E. Hammitt. 1995. Interpretive motivations and preferences of campfire program participants on the Blue Ridge Parkway. Legacy May/June:14-17.

Borg, W. R., and M. D. Gall. 1989. Educational research. Longman, New York.

Bureau of Economic and Business Research. 1992. Florida statistical abstract. College of Business Administration, University of Florida, Gainesville.

Cable, T. T., and D. M. Knudson. 1983. Interpretation as a management tool—the manager's view. Proceedings of the 1983 National Association of Interpreters workshop: advances in interpretation. West Lafayette, Indiana. National Association for Interpretation Publication, Fort Collins, Colorado.

Decker, D. J. 1990. Wildlife management—for whom and for what? Wildlife managers' use of social values indicators. Pages 713-721 in Transactions of the 19th International Union of Game Biologists Congress, Trondheim, Norway.

Dillman, D. A. 1983. Mail and other self-administered questionnaires. Pages 359-376 in P. H. Rossi, J. D. Wright, and A. B. Anderson, editors. Handbook of survey research. Academic Press, San Diego.

Duda, M. D. 1987. Floridians and wildlife: sociological implications for wildlife conservation in Florida. Technical report no. 2. Florida Game and Fresh Water Fish Commission, Tallahassee, Florida.

Duffus, D. A., and P. Dearden. 1990. Non-consumptive wildlife-oriented recreation: a conceptual framework. Biological Conservation 53:213-231.

Dunlap, R. E., G. H. Gallup, Jr., and A. M. Gallup. 1993. Health of the planet: results of a 1992 international environmental opinion survey of citizens in 24 nations. Gallup International Institute, Princeton, New Jersey.

Fink, A., and J. Kosecoff. 1985. How to conduct surveys. SAGE Publications, Beverly Hills, California.

Gigliotti, L. M. 1990. Environmental education: What went wrong? What can be done? Journal of Environmental Education 21(2):9-12.

Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology 8:27-38.

Hammitt, W. E. 1984. Cognitive processes involved in environmental interpretation. Journal of Environmental Education 15(4):11-15.

Hardesty, J. L. 1994. An introduction to ecosystem-based natural resource management. Pages 51-61 in J. L. Hardesty and S. L. Murin, compilers. Research report, Eglin Air Force Base, Florida: 1989-1994. The Nature Conservancy, Gainesville, Florida.

Hungerford, H., and T. Volk. 1990. Changing learner behavior through environmental education. Journal of Environmental Education 21(3): 8-21.

Jackson, J. J. 1982. Public support for nongame and endangered wildlife management: which way is it going? Transactions of the North American Wildlife and Natural Resources Conference 47:432-440.

Jacobson, S. K., editor. 1995*a*. Conserving wildlife: international education and communication approaches. Columbia University Press, New York.

Jacobson, S. K. 1995*b*. Needs assessment techniques for environmental education. International Research in Geographical and Environmental Education 4(1):125-133.

Jacobson, S. K. 1991. Evaluation model for developing, implementing, and assessing conservation education programs: examples from Belize and Costa Rica. Environmental Management 15(2):143-150.

Jacobson, S. K. 1990. A model for using a developing country's park system for conservation education. Journal of Environmental Education 22(1):19-25.

Jacobson, S. K. 1988. Media effectiveness in a Malaysian Park System. Journal of Environmental Education 19(3):22-27.

Kellert, S. R. 1980*a*. American's attitudes and knowledge of animals. Transactions of the North American Wildlife and Natural Resources Conference 45:111-124.

Kellert, S. R. 1980*b*. What do North Americans expect of wildlife management agencies? International Association of Fish and Wildlife Agencies 70:29-38.

Kim, J.-O., and C. W. Mueller. 1978. Factor analysis: statistical methods and practical issues. SAGE Publications, Beverly Hills, California.

Marradi, A. 1981. Factor analysis as an aid in the formation and refinement of empirically useful concepts. Pages 11-50 in D. J. Jackson and E. F. Borgatta, editors. Factor analysis and measurement in sociological research. SAGE Publications, Beverly Hills, California.

McDonough, M. H., and T. Lee. 1990. Evaluation of interpretive services: what do we know in 1990? Pages 333-340 in D. L. Kulhavy and M. H. Legg, editors. Proceedings of the 1990 National Associa-

ion of Interpreters workshop. What's past is prologue: our legacy, ›ur future. Charleston, South Carolina. National Association for Interpretation Publication, Fort Collins, Colorado.

er, T. L. and M. A. Miller. 1991. Citizen surveys: how to do them, ›ow to use them, what they mean. International City/County Management Association, Washington, D.C.

ts, P. H. 1983. An assessment of visitor interests and evaluation of conducted interpretive programs at Everglades National Park. M.S. thesis. Pennsylvania State University, State College.

ional Opinion Research Center. 1995. Environmental and scientific knowledge around the world. National Opinion Research Center, University of Chicago, Chicago, Illinois.

ss, R. F., E. T. LaRoe, III, and J. M. Scott. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Biological report 28. U.S. National Biological Service, Washington, D.C.

5 Institute. 1988. SAS/STAT user's guide, release 6.03 edition. SAS Institute, Inc., Cary, North Carolina.

ıw, W. W., and W. R. Mangun. 1984. Nonconsumptive use of wildlife in the United States: an analysis of data from the 1980 national survey of fishing, hunting, and wildlife-associated recreation. U.S. Fish and Wildlife Service Resource Publication 154, Washington, D.C.

eatsley, P. B. 1983. Questionnaire construction and item writing. Pages 195-230 in P. H. Rossi, J. D. Wright, and A. B. Anderson, editors. Handbook of survey research. Academic Press, San Diego, California.

Siehl, G. H. 1991. Natural resource issues in national defense programs. Congressional Research Service, Library of Congress, Washington, D.C.

Slocombe, D. S. 1993. Implementing ecosystem-based management: development of theory, practice, and research for planning and managing a region. BioScience 43:612-622.

Times Mirror Magazines. 1994. National environmental survey. Times Mirror Magazines, New York.

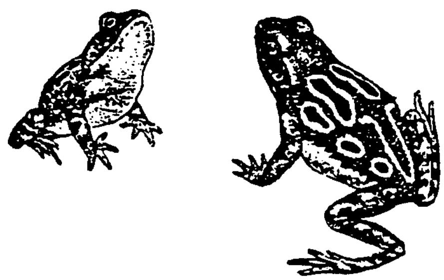
U.S. Air Force. 1993. Natural resources management plan, Eglin Air Force Base, Florida. Air Force Development Test Center, Eglin Air Force Base, Florida.

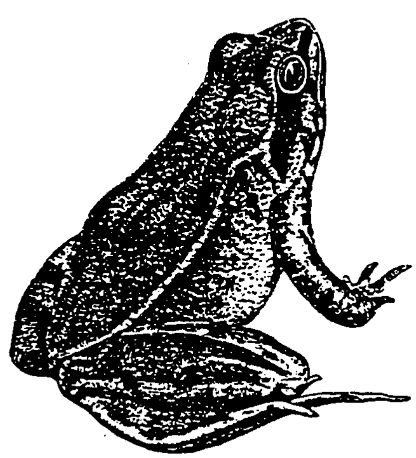
U.S. Fish and Wildlife Service. 1989. Analysis of the 1985 national survey of fishing, hunting, and wildlife associated-research: wildlife-related recreation on public lands, 1985. Report 85-3. U.S. Fish and Wildlife Service, Washington, D.C.

U.S. Fish and Wildlife Service. 1988. 1985 national survey of fishing, hunting, and wildlife associated recreation. U.S. Fish and Wildlife Service, Washington, D.C.

U.S. Fish and Wildlife Service. 1982. 1980 national survey of fishing, hunting, and wildlife associated recreation. U.S. Fish and Wildlife Service and U.S. Bureau of the Census, Washington, D.C.

Witter, D. J., and W. W. Shaw. 1979. Beliefs of birders, hunters, and wildlife professionals about wildlife management. Transactions of the North American Wildlife and Natural Resources Conference 44:298-305.





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Ecosystem management education for public lands

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Abstract An ecosystem management education program targeted at specific audiences was designed for Eglin Air Force Base in northwest Florida. The program was developed through a comprehensive, adaptive model, which incorporated data from baseline surveys and input from natural resource managers and key stakeholders. The educational program resulted in significant improvements in knowledge and attitudes among important constituencies (recreational users and neighboring citizens) of this large, multiple-use, public land holding. The targeted ecosystem education program at Eglin included 1,128 treatment and 1,127 control subjects in a randomized experimental design. Evaluative (post-treatment) surveys revealed that both direct and mass educational approaches were effective in increasing knowledge, and that mass media contributed most to shifts in attitudes. We include recommendations to improve knowledge and change attitudes about ecosystem management, identify and target key audiences, and monitor long-term program outcomes.

Key words ecosystem management, environmental education, evaluation, human dimensions, natural resources management

Introduction

Ecosystem management must integrate scientific knowledge with social values if it is to meet the long-term goal of maintaining and protecting native biodiversity (Bengston 1994, Grumbine 1994, Reading et al. 1994). The shift toward ecosystem management on public lands in the United States brings about changes in field practices that affect recreational users and neighboring citizens. For example, restoring fire-dependent pine ecosystems entails increased prescribed burning. While prescribed fire may accomplish specific management objectives, smoke and temporarily degraded landscapes can engender negative attitudes among citizens who are unaware of the ecological benefits of fire disturbance. While ecosystem management goals may focus on biological problems, agency actions must include the application of sociological data in programs tailored to affect people's knowledge, attitudes, or behaviors in relation to land management, in order to achieve those ecosystem management objectives.

Complicating the shift toward ecosystem management is an overall trend of expanding demand for outdoor recreation in the United States (United States Fish and Wildlife Service 1982, 1988). This is especially true in Florida, where the population is rapidly increasing and tourism rates are high (Duda 1987). Ecosystem education efforts are particularly needed in areas where many citizens are newcomers who lack the long-term perspective necessary to realize how dramatically the environment has changed (Duda et al. 1989).

This growing pressure on public lands requires more intensive management and public education to maintain recreational opportunities without permanent harm to finite natural resources. Education can modify behaviors, increase the effective carrying capacity of recreational areas, and bolster public support for land protection policies (Cable and

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Knudson 1983). The public expects and is supportive of the involvement of government land management agencies in such educational efforts (Dunlap et al. 1993). According to Duda (1987), adult recreational users of public lands in Florida are an audience particularly ripe for ecosystem education; not only are they more supportive of natural resource management than average citizens, they are also more likely to want additional information.

Recreationists impact public lands not only by direct use but also by influencing land management policies and decisions (Jacobson 1990). Environmentally responsible and knowledgeable citizens are essential in building public support for land management plans. High levels of public involvement are characteristic of the new ecosystem management schemes, which generally seek to integrate public involvement into a comprehensive system of planning, decision-making, research, and management (Hardesty 1994). Nonformal adult education programs have potential to improve knowledge and change attitudes in citizens who influence natural resource management on public lands.

The United States public expresses affection and concern for wildlife conservation and environmental protection. Seventy percent of respondents to an ABC News-*Washington Post* poll (1995) think that the government has not gone far enough in protecting the environment. A recent poll of Floridians revealed that over 83% of citizens want as much or more time and money spent on endangered species conservation in the future as in the past (Florida Game and Fresh Water Fish Commission 1995). Yet while levels of public environmental appreciation are high, basic ecological knowledge is low (Gigliotti 1990).

For the past decade, conservation scientists have called for effective education programs to build an ecological knowledge base for the public's supportive attitudes, and to encourage pro-environmental behaviors and public involvement (Noss and Cooperrider 1994, Orr 1994, Jacobson 1991). Most studies to date have explored public education programs on a limited or non-experimental basis. Some studies have examined programs targeted to recreational users at restricted public preserves such as state parks (e.g., Olson et al. 1984). Other researchers have studied hunters' satisfactions and opinions across a state or region (e.g., Enck and Decker 1991, Duda and Young 1993). This study experimentally evaluates an education program for a wide range of constituents of a single, large, multiple-use, public land holding with a new ecosystem management focus.

A public education program to further ecosystem management and resource conservation goals was implemented for a variety of constituents of Eglin Air Force Base, Florida. The Department of Defense (DOD) has recently changed the direction of its stewardship on military bases to ecosystem management. Although educational programs as a recreational and management activity have not been a traditional part of DOD objectives or actions, as they have at other United States parks and forests (Adams and Hammitt 1995), public education was identified as one of 8 key components to enhance ecosystem management goals in Eglin's Natural Resources Management Plan (United States Air Force 1993). Eglin's large size, ecological significance, diverse user groups, and surrounding urban and rural population of over half a million make it ideally suited to test a comprehensive public lands ecosystem education program.

Grumbine (1994) calls for experimental verification of the value of a variety of forms of conservation education to ecosystem management programs. The goal of this study was to develop and experimentally test methods of communication about principles and topics of ecosystem management for Eglin's recreational users and neighboring citizens within a comprehensive and adaptive public education model. Project goals were to measurably increase knowledge about ecosystem management topics, promote favorable attitudes, and foster behavior promoting ecosystem management objectives at Eglin. We hypothesized that the educational program would result in: (1) H_1: increased knowledge about ecosystem management, and (2) H_2: more favorable attitudes toward ecosystem management, as measured by comparing survey scores of treatment and control subjects with the *t*-test and by comparing baseline and evaluative survey scores of subjects within the treatment group with the paired *t*-test. In addition, we tested the effectiveness of various educational approaches and media.

Methods

Program model

The study was based on a systematic model of program development and evaluation (Jacobson 1990) (Figure 1). Similar to how ecosystem management has been applied at Eglin, this model takes an adaptive, or iterative, approach to developing,

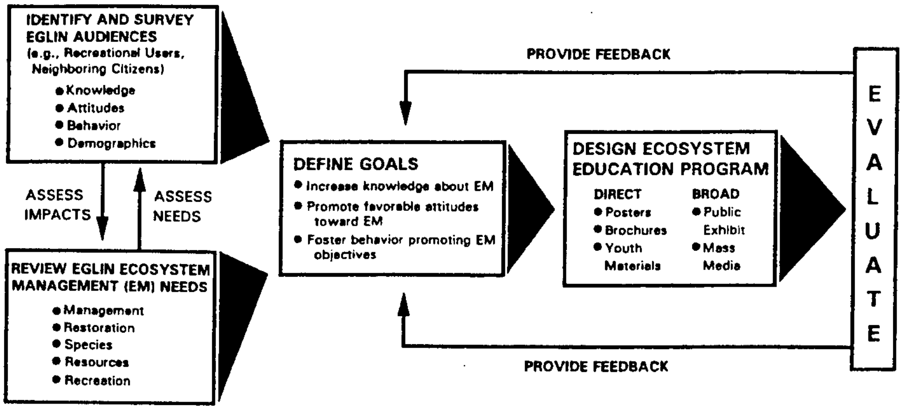

Figure 1. Model for designing and evaluating the targeted ecosystem management (EM) education program at Eglin Air Force Base.

implementing, and evaluating a public education program. Preliminary work involved: (1) reviewing ecosystem management needs based on information gathered from Eglin's Natural Resources Management Plan, interviews with Natural Resources Division staff, and consultation with outside experts, and (2) a 1993 baseline survey of Eglin's recreational users and neighboring citizens to measure existing knowledge and attitudes toward wildlife conservation and ecosystem management (Jacobson and Marynowski 1997). Before this research, knowledge levels and attitudes of Eglin recreational users and citizen neighbors were unknown.

From the information-gathering activity, we determined that the education program should concentrate on 4 key content areas: endangered species, the ecological role of fire, ecosystem management, and forest resources and recreation. The ecosystem education program was targeted to the user and citizen audiences through a process that combined baseline survey results with ecosystem management needs within the 4 identified content areas. Because user and citizen audiences displayed very similar demographic profiles on the baseline surveys, they were targeted with the same educational treatment and results are combined.

Specific media were selected and designed to reach the geographically dispersed audiences, to fit within existing programmatic constraints, and to address knowledge and attitudes in the key content areas at the level measured by the baseline surveys. The Eglin public education program concentrated on ecological literacy and ecosystem education needs similar to those identified by other conservation education researchers (e.g., Gigliotti 1990, Pomerantz 1991, Francis et al. 1993). Through this targeting procedure, the educational program reached audiences at the appropriate level, and built upon existing knowledge and attitude levels.

Methods selected were representative of mass public education efforts over broad geographic areas. Selected media were separated into 2 major groups based on delivery system: (1) direct approaches; which included posters, brochures, and a youth activity booklet mailed directly to participants; and (2) broad approaches; which included mass media coverage (newspaper, television, and radio) and presentation of a portable exhibit at public events. How well the education program met the project goals was evaluated by comparing results of the evaluative survey of knowledge and attitudes to control-group and baseline-survey measurements. We also evaluated the effectiveness of the 2 different delivery systems (direct vs. broad) and the effectiveness of the individual educational media.

Study site

The DOD mission at Eglin is to develop and test conventional munitions and sensor systems for the United States Air Force. At 185,600 ha, Eglin is the largest forested military installation in the western hemisphere. Approximately 60% of Eglin is open for permitted public recreational use, including opportunities for hiking, hunting, fishing, picnicking, canoeing, bicycling, and nature observation. Recently, Eglin has issued nearly 15,000 recreational permits/year and has approximately 20,000 user visits/year. Over 515,000 people live in surrounding Escambia, Santa Rosa, Okaloosa, and Walton counties of the Florida panhandle.

Initial biological inventories indicate that Eglin contains over half of Florida's 81 natural community types (Florida Natural Areas Inventory and Florida Department of Natural Resources 1990, Florida Natural Areas Inventory 1995). Eglin protects one of the largest remaining contiguous longleaf pine (*Pinus palustris*) forests, a critically endangered ecosystem type of the southeastern United States (Noss et al. 1995). Inhabitants of Eglin include 22 animal and 67

plant species that are endangered, threatened, rare, or of special concern (United States Air Force 1993).

Experimental design, surveys, and statistical analysis

The study followed a Solomon 4-group experimental design to assess effects of the educational treatment while controlling for effects of a baseline survey (Figure 2). The 4-group design is a 2-by-2 factorial experimental design, with one factor being the presence or absence of the baseline survey, and the other factor being the treatment vs. control. The research employed surveys of recreational user and citizen populations. We randomly selected samples of (1) permitted Eglin recreational users, and (2) heads-of-households from the 4-county area within a 30-mile radius of Eglin. Selected participants were randomly assigned to treatment or control conditions, and only half of each group was exposed to the baseline survey.

An iterative survey design process was used to determine survey content; draft questions; format the questionnaire; review, pretest, and implement the instrument as a baseline survey; and to revise the survey for educational program evaluation. Questions were designed to measure knowledge and attitudes in relation to the 4 key content areas defined through preliminary review and the baseline surveys. Attitude questions were designed around a symmetric, 5-point, Likert-type scale (1=strongly disagree to 5=strongly agree) with a central neutral category. Knowledge questions were designed to measure familiarity or awareness in a true-false format. The evaluative survey consisted of 4 core sections: 18 attitude questions, 12 knowledge questions 9 questions about outdoor recreational behaviors and interests, and 6 sociodemographic questions. The evaluative survey also included a series of questions to ascertain which educational materials a respondent remembered seeing and additional questions for long-term monitoring purposes. As recommended by Dillman (1983), surveys and a reminder were repeated in 3 mailings to maximize response rates.

Evaluation of the effect of the education program for knowledge and attitude hypotheses was based on: (1) t-test comparisons between mean evaluative survey scores of treatment and control subjects on knowledge and attitude dimensions, and (2) paired t-test comparisons of mean baseline and evaluative survey scores for individuals within the treatment group on knowledge and attitude dimensions. A factor analysis of the core attitude questions on the baseline and evaluative surveys had indicated that the items could be grouped into 4 composite scores parallel to the 4 key content areas (Marynowski 1995). Knowledge questions were similarly reported for 4 composite scores and an overall knowledge score. Analysis was done with an SAS statistical package (SAS Institute 1988).

Four Group Experimental Design

O = Survey Observation X = Educational Treatment

	1993 Baseline Survey	1993-1995 Educational Treatment	1995 Evaluative Survey
1	O	X	O
2	O		O
3		X	O
4			O

Figure 2. The 4-group experimental design included randomly selected and assigned subjects in treatment and control groups. The design controls for bias by exposing only half of each group to the baseline survey and for error by bringing in new participants partway through the study.

In the evaluation of the effects of the educational approaches and individual media, evaluative survey knowledge and attitude scores were used as dependent variables in a series of ANOVAs. The ANOVAs compared evaluative survey scores of subjects who reported seeing educational materials vs. those who did not report seeing educational materials, regardless of treatment or control-group membership. This was appropriate to test the effects of the individual educational media, after the experimental test of the overall educational program. Because some respondents had seen more than one type of media, the media were evaluated in the ANOVAs as dichotomous independent variables (i.e., whether or not a participant had been exposed to a given educational medium). Preliminary tests showed no 2-way interactions between media variables, so each ANOVA tested only for the main effects of each educational approach or medium on knowledge or attitude scores. Individual media tested as independent variables were: brochure, poster, youth activity booklet, exhibit, and mass media. The mass media variable combined television, radio, and print journalism coverage, as there were not enough cases to separately test mass media subcategories. Educational media also were grouped into two educational approaches and tested as independent variables

(direct and broad) to make recommendations for future methods of reaching Eglin audiences.

Education program

Educational materials addressed specific knowledge and attitude elements within the 4 key content areas identified through the baseline survey and included information about principles of ecosystem management, communities and species present on Eglin, the role of disturbances such as fire in ecosystem function and restoration, characteristics of mature longleaf pine forests, human uses and behaviors compatible with Eglin's ecosystems, and information to facilitate outdoor recreation and wildlife observation. To promote favorable field behavior of Eglin visitors, materials also included recommendations for specific environmentally friendly actions.

Educational materials were developed following standard guidelines for program success: organized structure; repetitive presentation of the message; credibility, expertise, and trustworthiness of the source; and concrete avenues for active participation of target audiences (e.g., Vaughn 1983). Visually, the materials were colorful and attractive, including color photographs where affordable (poster, exhibit) and line illustrations printed on colored paper (brochures, youth activity booklet).

Sociodemographic data from the baseline survey identified the recreational user and citizen audiences as similar to each other and as more middle class, better educated, and older than typical area citizens (Bureau of Economic and Business Research 1992). Reflecting the area population, respondents were mostly white. Most baseline survey respondents were male, in keeping with the recreational user and head-of-household populations sampled. Consequently, materials were targeted specifically to these audiences within the goals of the educational program. For example: brochure illustrations depicted a diversity of people but prominently featured members of the target audiences involved in activities popularly reported on the baseline survey, such as walking, hunting, fishing, and boating; vocabulary was geared toward the educational level of the audiences; and a focus was maintained on the military mission and a sense of patriotism throughout the materials, because most audience members reported being directly or indirectly employed by the DOD. The poster included a calendar to enhance its usefulness to the many audience members who reported professional-level training and employment.

The targeted educational program included both direct approaches (posters, brochures, youth activity booklets) and broad approaches (mass media, portable exhibit). Direct materials were delivered during spring 1994 to all treatment subjects in 3 separate first-class mailings: the poster, the set of 4 brochures, and the youth activity booklet. Each mailing was accompanied by a short note identifying the source and inviting the recipient to read and share the material. Broad educational approaches were widely distributed to the area population. News releases were circulated to area media and wire services by Eglin's Environmental Public Affairs office from summer 1993 through the end of 1994, resulting in at least 6 television stories and 63 print media articles. The portable exhibit was presented at 4 major public events in fall 1994, attended by over 35,000 people.

We randomly assigned 1,128 recreational users and neighboring citizens to receive the direct educational treatment; 1,127 served as control subjects. Half of the subjects in the treatment and control groups were not exposed to the baseline survey. Although some control subjects were inadvertently exposed to the broad educational approaches, experimental randomness was maintained and they were not removed from the study. Therefore, the reported results remain conservative in nature. Many respondents were exposed to more than 1 educational media, and this was accounted for through the ANOVA analysis.

Results

The overall response rate to the evaluative survey was 47% (n=907, 15% undeliverable), with a mean standard error of 2.60% for all knowledge and attitude items. These results are similar to the response and error results of our baseline survey (51% overall response rate: Jacobson and Marynowski 1997) and to other natural resource survey results (McDonough and Nelson 1989, Purdy and Decker 1989). The surveys were designed and implemented to minimize sources of error. Coverage error was eliminated by drawing names from complete lists of target survey populations, sampling error was reduced through random sampling and a larger-than-recommended sample size, and measurement error was minimized through a careful and unbiased questionnaire design subjected to expert review and pretesting among the population (Salant and Dillman 1994). Nonresponse bias was addressed by following

recommended survey design methods to maximize response rates (Salant and Dillman 1994).

The evaluative survey response rate indicates that there may be a problem with nonresponse bias. Although we were unable to measure nonrespondents to test for nonresponse bias, we have no evidence that nonrespondents were different from respondents judging from: (1) the homogenous population in the area (Bureau of Economic and Business Research 1992), and (2) the similarity of baseline and evaluative survey respondents within the 4-group experimental design to each other and to the area population. Because of these factors, we believe that the significance of nonresponse bias to our results is minimal.

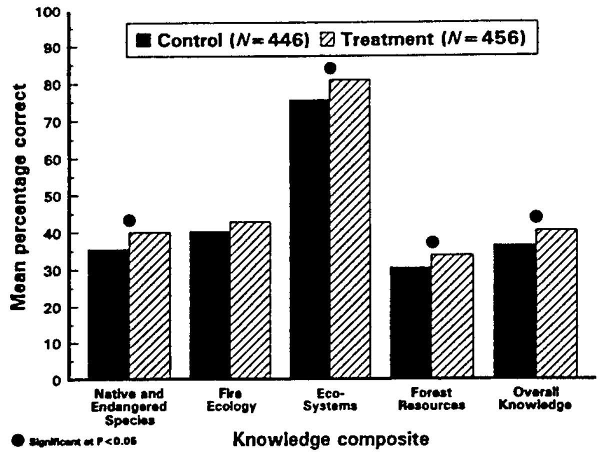

Figure 3. *T*-test comparison of mean knowledge levels of treatment and control subjects based on evaluative survey scores. Bullets indicate significant differences at $P<0.05$.

Audience sociodemographics

Evaluative survey respondents were more educated than the general population of the 4-county Eglin area: 33% of evaluative survey respondents held 4-year or graduate college degrees, compared to 12-21% of area residents with college degrees. Because survey populations were Eglin recreational users and area heads-of-households, most evaluative survey respondents were male (82%) and older (50) than the median age (32-38) for Escambia, Okaloosa, Santa Rosa, and Walton counties. Respondents were overwhelmingly white (96%), not surprising in a 4-county area with a 77-94% white population (Bureau of Economic and Business Research 1992). These demographic results were similar to those of the baseline survey (Jacobson and Marynowski 1997).

Knowledge and attitudes

The analysis of the educational treatment and the paired comparison of baseline and evaluative survey results showed that the educational treatment was effective in improving all areas of knowledge (H_1), and that it had a positive effect on overall attitudes (H_2). Treatment subjects had significantly higher knowledge scores in the areas of native and endangered species, ecosystem management, forest resources, and overall knowledge (Figure 3). Respondents who received the treatment knew significantly more about native and endangered species than did control subjects (t=2.87, P=0.0042). Respondents also scored significantly better on measures concerning forest resources (t=2.16, P=0.031), and marginally better on ecosystem questions (t=1.95, P=0.0513). On overall knowledge, the treatment group scored significantly better than control subjects (t=3.01, P=0.0027).

Treatment and control groups did not differ significantly regarding attitudes as measured by a t-test of evaluative survey scores, although there was a tendency in the raw data toward more positive attitudes. However, when comparing baseline and evaluative survey scores for individual subjects within the treatment group using the more powerful paired t-test, overall attitudes became significantly more favorable for treatment subjects from baseline (3.43) to evaluative survey (3.53, paired t=3.26, P=0.0013). A paired t-test comparing baseline and evaluative scores of control subjects showed no similar significant shift in overall attitudes. Overall, evaluative survey respondents expressed their most favorable attitudes toward forest resources (3.7), whereas other mean attitude scores ranged from 3.3 to 3.5 (on a scale of 1=strongly disagree to 5=strongly agree).

Effects of educational media

The specific effects of each educational medium were examined based on responses to evaluative survey questions about which media a participant had seen. Media were tested as a group of dichotomous independent variables in ANOVAs with overall knowledge and attitude scores as dependent variables. The poster, brochures, youth booklets, and mass media all contributed to improvements in overall knowledge scores (F=26.93, P<0.001), while the poster and mass media contributed to more favorable overall attitudes (F=5.55, P<0.001) (Figure 4).

In the separate knowledge composite areas, brochures and mass media accounted for significant improvements in knowledge of endangered and

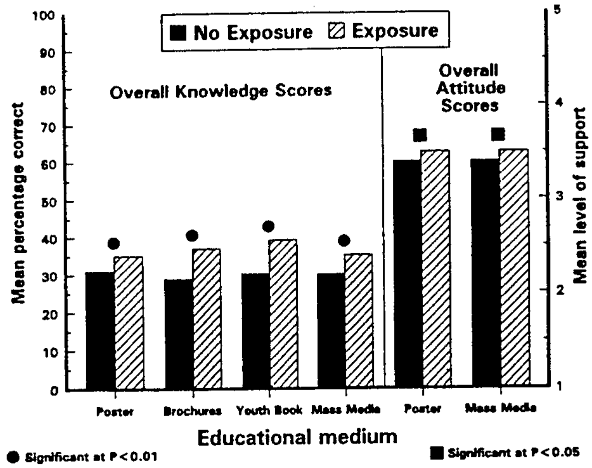

Figure 4. Individual educational media that had a significant effect on overall knowledge (left axis, $P<0.01$) and attitudes (right axis, $P<0.05$) of respondents. Only significant media are shown. Each case has a unique "no media" bar because each ANOVA individually tested each medium as a dichotomous variable.

native species ($F=25.39$, $P<0.001$); the poster, brochures, and mass media improved knowledge of fire ecology ($F=11.23$, $P<0.001$); brochures improved knowledge of ecosystems ($F=5.87$, $P<0.001$); and brochures, youth activity booklets, and mass media increased forest resources knowledge ($F=7.78$, $P<0.001$). In the separate attitude composite areas, brochures influenced attitudes concerning forest resources ($F=3.21$, $P=0.0071$), brochures and mass media influenced attitudes toward ecosystems ($F=4.55$, $P<0.001$), and the poster and mass media influenced attitudes toward native and endangered species ($F=2.91$, $P=0.013$) and fire ecology ($F=2.74$, $P=0.018$).

Effects of educational approaches

The effects of the broad and direct educational approaches also were examined based on which media each participant reported seeing. Based on the ANOVA, both direct and broad approaches contributed to improved knowledge scores (Figure 5a). Direct and broad approaches each had a significant impact on improved knowledge of native and endangered species ($F=33.72$, $P<0.001$), fire ecology ($F=13.42$, $P<0.001$), and forest resources ($F=10.23$, $P<0.001$). Direct approaches had a significant effect on knowledge of ecosystems ($F=9.31$, $P<0.001$). Both direct and broad approaches had significant effects on overall knowledge scores ($F=36.38$, $P<0.001$).

The direct and broad approaches had a less pronounced effect on attitudes (Figure 5*b*). Direct materials influenced attitudes toward forest resources ($F=4.65$, $P=0.0031$). Broad approaches led to more favorable overall attitudes ($F=3.80$, $P=0.01$).

Discussion

The targeted ecosystem education program at Eglin Air Force Base was effective in improving knowledge and promoting favorable attitudes among recreational users and neighboring citizens. Both direct and broad educational approaches were effective in building knowledge, and broad approaches contributed most to more favorable overall attitudes. Several educational media (posters, brochures, youth activity booklets, and mass media) were effective in raising knowledge levels, and posters and mass media contributed most to more favorable attitudes. Significant treatment effects were found despite the proportion of control subjects (19–34%) who reported seeing various broadly disseminated educational materials.

Improving knowledge and attitudes

The education treatment had a significant effect in improving content area and overall knowledge scores, satisfying the objective of this project to increase knowledge levels about key ecosystem management topics among target audience members. Educational media were particularly effective in influencing knowledge about native and endangered species and fire ecology. For example, positive results were achieved in the recognition of Eglin's endangered red-cockaded woodpecker (RCW), rising from a 31% baseline to 48% evaluative survey knowledge level. More treatment respondents knew that RCWs nest in old trees (34%, baseline: 26%). Overall endangered-species knowledge rose from 26% on the baseline survey to 39% on the evaluative survey. Knowledge of fire ecology also improved: 42% of respondents were aware that regular fire maintains a natural balance of pine and oak trees (baseline: 34%), 62% said that regularly burned forests are useful for native wildlife (baseline: 56%), and 50% knew that fire is beneficial for native plants (baseline: 47%).

Knowledge of forests and ecosystems was in some cases very high on the baseline survey, and so did not show as much improvement on the evaluative survey. For example, 66% of respondents to both surveys knew that large pine trees are a component of mature forests on Eglin, and 80% of

respondents to both surveys recognized that riparian corridors are important for wildlife.

Although some measures either improved or showed high levels of preexisting knowledge, other knowledge content areas reflected the relatively low levels of basic ecological understanding reported by so many researchers (e.g., Kellert 1980*b*, Gigliotti 1990, Manfredo et al. 1990). For example, only 28% of evaluative survey respondents identified Eglin's most widespread native tree species, the longleaf pine, which is a focus of forest ecosystem restoration efforts on Eglin. Even fewer respondents identified regular fire (15%) and thick grasses (17%) as components of Eglin's mature pine forests. Only 30% of respondents to both surveys knew that RCWs nest in living pine trees. These low levels of ecological knowledge of Eglin's pine forests, fire ecology, and endangered species must be improved if the public is to understand the importance of and support ecosystem restoration of old-growth longleaf pine forests for endangered species and for future generations of human use.

Public ecological literacy has been of concern to researchers for many decades. Daniel (1990) identifies public misunderstanding of fire ecology as a major obstacle to acceptance of prescribed burning, and recommends increased education on the ecological benefits of fire. Kellert (1980a) recommends that education programs communicate information about the environment as a system and the relationships between wildlife species and natural habitats. Francis et al. (1993) recommend educating people in underlying ecological principles to promote better understanding of natural resources. Based on the survey results, there clearly is a need for continued attention to basic ecological education at Eglin. Ecological literacy must continue to be improved with basic education addressing the components, structures, and functions of ecosystems, as well as more pressing issues that require immediate public attention to management actions.

In addition to addressing knowledge, education programs also must include specific tactics to promote more favorable attitudes. For example, Pomerantz (1991) concludes that conservation education programs should address not only knowledge about wildlife and management practices but also attitudes of stewardship for the environment. Other education guidelines emphasize making connections between ecological information and the human activities that affect ecological systems. Gigliotti (1990) calls for practical conservation education in

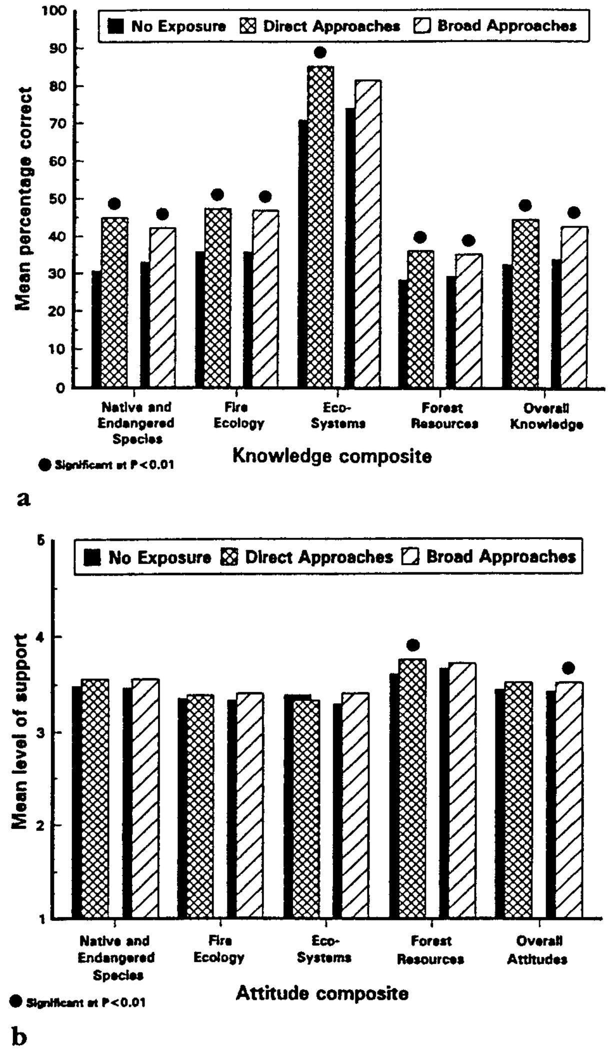

Figure 5. Effects of direct and broad educational approaches on (*a*) knowledge and (*b*) attitudes of respondents. Bullets indicate significant effects at $P<0.01$. Each case has a unique "no media" bar because each ANOVA individually tested each approach as a dichotomous variable.

support of management goals, addressing issues of the impacts of human behaviors on biological communities and the interdependence of humans and natural resources. While many behavioral problems on Eglin are enforcement issues beyond the scope of the ecosystem education program, it is hoped that improved knowledge and attitudes will influence the future behavior of Eglin audiences.

The attitude enhancement that resulted from the educational program met the objective of this research to reinforce positive public attitudes toward ecosystem management. However, despite the somewhat supportive attitudes and significant overall

attitude improvement seen in the paired analysis, attitude shifts resulting from the educational program were incremental. While overall attitudes were significantly more favorable, results within the separate attitude content areas on the paired analysis were mixed: Both treatment and control respondents showed more favorable attitudes toward endangered species and fire ecology, which had lower levels of baseline support, and less favorable attitudes toward ecosystems and forest resources, which had higher levels of baseline support. In effect there was a moderation of attitudes, one possible outcome that is predicted as a result of increased knowledge levels (Shrigley et al. 1988). This underlines the sometimes indirect relationship between knowledge and attitudes, and emphasizes the need for ecosystem education programs that specifically address attitudinal dimensions. The shifts in attitudes among members of the control group also may reflect the exposure of control respondents to the broadly distributed mass media components of the program, which were shown to be most effective in influencing overall attitudes (Figure 5*b*).

Alternative educational approaches can be tested at Eglin in the future to more strongly influence attitudes and behaviors of recreational users and citizens. Ventures such as informal experiential outdoor group activities are effective at improving short- and long-term attitudes, eliciting environmentally sound behaviors, and increasing the likelihood of seeking further information (Lisowski and Disinger 1991, Tamir 1991, White and Jacobson 1994). Continuity and repetition also have been identified as key elements in the success of educational endeavors addressing knowledge, attitudes, and behaviors (Hungerford and Volk 1990, Dwyer et al. 1993, Hanson 1993). According to DeYoung (1993), heightened awareness, supportive attitudes, and environmentally sound behaviors can be generated by a number of education techniques, but are gradually eroded back to baseline conditions if not reinforced by the cumulative effects of multiple exposures to educational media.

In evaluating individual educational media, color posters and mass media significantly influenced attitudes. This reinforces the notion that readily available mass communications, particularly colorful and stimulating television and print journalism, have the power to shift attitudes—where a factual publication may not—by exciting visual attention, invoking emotion, and introducing people to new ideas and concepts. The least successful program element was the public exhibit, which showed no significant effects on knowledge or attitude scores. Time-consuming and labor-intensive exhibits that impact very broad audiences in a cursory way could be abandoned in favor of more successful targeted publications, mass media, and site-specific exhibits and interpretation.

Targeting audiences

With the increasing demand for recreational opportunities on public lands, an understanding of social variables and educational approaches will be critical to meet management goals of balancing recreational opportunities with resource protection. According to Duffus and Dearden (1990), strategies to deal with increasing and shifting demands on natural resources include gaining knowledge of users, integrating biological and social values information, and modifying recreational behaviors to meet management goals. Applied knowledge of target audience social variables was key to developing and testing effective educational approaches during this time when Eglin was experiencing increased demand and expanding into new ecosystem management program areas. Eglin natural resource managers may further use the social data collected in this study to formulate management objectives, solve management problems, and adopt socially acceptable actions within the ecosystem management framework (e.g., Decker 1990, Slocombe 1993). Where traditional land managers once viewed social research and public education as superfluous, these techniques must be increasingly employed as pivotal management tools.

Because of their strongly held opinions and regular contact with natural resources, recreational user groups remain a priority audience for education programs. Eglin survey results showed that recreational users held more strongly positive and negative opinions about resource management issues, whereas neighboring citizens held more moderate or neutral opinions (Jacobson and Marynowski 1995). In a review of the literature, Marcinkowski (1993) concludes that improved knowledge among resource users not only will lead to increased enjoyment but also can influence environmental attitudes and behavior. Because Eglin's recreational users are more experienced with the environment, more knowledgeable about natural resources, and more opinionated and outspoken than Eglin's neighboring citizens about resource management issues, they

are more likely to actively support or denigrate resource management programs. Educational programs for public lands also must continue to address the awareness and support of neighboring citizens and decision-makers, particularly around critical management issues such as prescribed burns and wildlife management where public opinion and policy play an important role.

Monitoring program outcomes

Target audiences must be monitored over time to provide regular measures of knowledge, attitudes, and satisfaction levels. Researchers have found that where knowledge and attitude changes did not immediately develop from educational programs, levels sometimes improved significantly over a time period of 1 to 6 years (Perdue and Warder 1981, Hanson 1993). Now that baseline and evaluative survey research has been completed and has validated Eglin's public ecosystem education effort, a follow-up monitoring strategy is being designed to confirm and improve the ongoing program. Just as monitoring of ecological systems is a key element of an ecosystem management program, social monitoring can be used by managers when reexamining education program goals, to identify key variables for monitoring long-term program success, to improve public involvement, and to increase audience acceptance of and satisfaction with new ecosystem management directions.

Conclusions

For successful ecosystem management, effective and ongoing communications must reach recreational consumers and the publics who may influence future policy direction. Management program visibility and motivated recreational audiences make education programs a good prospect for stimulating broad-based support for ecosystem management on public lands. We have demonstrated the usefulness of a comprehensive and adaptive educational model in developing ecosystem education programs that are effective at improving knowledge and enhancing attitudes among constituencies of a large, multiple-use, public land holding. This research has specifically illustrated the effectiveness in improving knowledge and attitudes of public education programs that are targeted to specific audiences and developed with data from baseline surveys, input from key stakeholders, and a review of ecosystem management needs.

These research results will be useful in developing conservation and ecosystem education programs for military reserves and other multiple-use public and private lands involved with shifting management objectives. This research serves as an experimental prototype to develop and assess educational programs to increase knowledge and improve attitudes of public lands constituencies. In view of the effectiveness of targeted education programs, the known benefits of continuity and repetition, and the continued need for basic ecological education, successful public lands education programs must incorporate targeted media in continual and repetitive program formats.

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Literature cited

ABC News/Washington Post. 1995. Poll. May 11-14, 1995.

Adams, A., and W. E. Hammitt. 1995. Interpretive motivations and preferences of campfire program participants on the Blue Ridge Parkway. Legacy May-June: 14-17.

Bengston, D. N. 1994. Changing forest values and ecosystem management. Society and Natural Resources 7:515-533.

Bureau of Economic and Business Research. 1992. Florida statistical abstract. University of Florida, College of Business Administration, Gainesville.

Cable, T. T., and D. M. Knudson. 1983. Interpretation as a management tool—the manager's view. Pages 26-33 *in* Proceedings of the 1983 workshop: Advances in interpretation. National Association of Interpreters, West Lafayette, Indiana.

Daniel, T. C. 1990. Social/political obstacles and opportunities in prescribed fire management. Pages 134-138 *in* Effects of fire management of Southwestern natural resources: Proceedings of the symposium. United States Forest Service General Technical Report RM-191, Washington, D.C.

DECKER, D. J. 1990. Wildlife management—for whom and for what? Wildlife managers' use of social values indicators. Pages 713-721 *in* Transactions of the Nineteenth Congress, International Union of Game Biologists, Trondheim, Norway.

DEYOUNG, R. 1993. Changing behavior and making it stick: The conceptualization and management of conservation behavior. Environment and Behavior 25(4):485-505.

DILLMAN, D. A. 1983. Mail and other self-administered questionnaires: The total design method. Pages 359-376 *in* P. H. Rossi, J. D. Wright, and A. B. Anderson, editors. Handbook of survey research. Academic, San Diego, California.

DUDA, M. D. 1987. Floridians and wildlife: Sociological implications for wildlife conservation in Florida. Florida Game and Fresh Water Fish Commission Technical Report Number 2.

DUDA, M. D., S. I. CERULEAN, AND J. A. GILLEN. 1989. Comprehensive wildlife education planning in Florida: The value of human dimensions research. Transactions of the North American Wildlife and Natural Resources Conference 54:455-467.

DUDA, M. D., AND K. C. YOUNG. 1993. Maryland licensed deer hunters: Opinions of a muzzleloading firearm deer season prior to the modern firearms deer season and other management topics: Final report. Maryland Department of Natural Resources, Wildlife Division, Annapolis.

DUFFUS, D. A., AND P. DEARDEN. 1990. Non-consumptive wildlife-oriented recreation: A conceptual framework. Biological Conservation 53:213-231.

DUNLAP, R. E., G. H. GALLUP, JR., AND A. M. GALLUP. 1993. Health of the planet: Results of a 1992 international environmental opinion survey of citizens in 24 nations. Gallup International Institute, Princeton, New Jersey.

DWYER, W. O., F. C. LEEMING, M. K. COBERN, B. E. PORTER, AND J. M. JACKSON. 1993. Critical review of behavioral interventions to preserve the environment: Research since 1980. Environment and Behavior 25(3):275-321.

ENCK, J. W., AND D. J. DECKER. 1991. Hunters' perspectives on satisfying and dissatisfying aspects of the deer-hunting experience in New York: An executive summary. Series #91-3 of the Human Dimensions in Natural Resources Unit, Cornell University, Ithaca, New York.

FLORIDA GAME AND FRESH WATER FISH COMMISSION. 1995. Floridians overwhelmingly back wildlife, environmental protection. News release: 27 November 1995.

FLORIDA NATURAL AREAS INVENTORY. 1995. Rare plant survey of Eglin Air Force Base, 1992-1994: Final Report. Florida Natural Areas Inventory, Tallahassee.

FLORIDA NATURAL AREAS INVENTORY AND FLORIDA DEPARTMENT OF NATURAL RESOURCES. 1990. Guide to the natural communities of Florida. Florida Natural Areas Inventory and Florida Department of Natural Resources, Tallahassee.

FRANCIS, M. G., R. E. BANNER, AND G. A. RASMUSSEN. 1993. A model for environmental education in natural resources. Journal of Environmental Education 24(4):22-25.

GIGLIOTTI, L. M. 1990. Environmental education: What went wrong? What can be done? Journal of Environmental Education 21(2):9-12.

GRUMBINE, R. E. 1994. What is ecosystem management? Conservation Biology 8(1):27-38.

HANSON, R. 1993. Long-term effects of the energy source education program. Studies in Educational Evaluation 19:363-381.

HARDESTY, J. L. 1994. An introduction to ecosystem-based natural resource management. Pages 49-61 *in* J. L. Hardesty and S. L. Murin, editors. Research report, Eglin Air Force Base, Florida: 1989-1994. The Nature Conservancy, Gainesville, Florida.

HUNGERFORD, H. R., AND T. L. VOLK. 1990. Changing learner behavior through environmental education. Journal of Environmental Education 21(3):8-22.

JACOBSON, S. K. 1990. A model for using a developing country's park system for conservation education. Journal of Environmental Education 22(1):19-25.

JACOBSON, S. K. 1991. Evaluation model for developing, implementing, and assessing conservation education programs: Examples from Belize and Costa Rica. Environmental Management 15(2):143-150.

JACOBSON, S. K., AND S. B. MARYNOWSKI. 1995. An ecosystem approach to public education and information at Eglin Air Force Base: Final report of the public and recreational users education program: 1993-1995. University of Florida, Department of Wildlife Ecology and Conservation, Gainesville.

JACOBSON, S. K., AND S. B. MARYNOWSKI. 1997. Public attitudes and knowledge about ecosystem management on Department of Defense lands. Conservation Biology 11(3):770-781.

KELLERT, S. R. 1980a. Americans' attitudes and knowledge of animals. Transactions of the North American Wildlife and Natural Resources Conference 45:111-124.

KELLERT, S. R. 1980b. What do North Americans expect of wildlife management agencies? International Association of Fish and Wildlife Agencies 70:29-38.

LISOWSKI, M., AND J. F. DISINGER. 1991. The effect of field-based instruction on student understanding of ecological subjects. Journal of Environmental Education 23(1):19-23.

MANFREDO, M. J., M. FISHBEIN, G. E. HAAS, AND A. E. WATSON. 1990. Attitudes toward prescribed fire policies. Journal of Forestry 88(7):19-23.

MARYNOWSKI, S. B. 1995. Ecosystem management education for public lands: A case study of Eglin Air Force Base, Florida. Thesis, University of Florida, Gainesville.

MCDONOUGH, M. H., AND C. M. NELSON. 1989. Public knowledge of forest practices: Understanding before education. Pages 428-433 *in* D. R. Hahn, editor. Proceedings of the 1989 workshop. National Association of Interpreters, St. Paul, Minnesota.

NOSS, R. F., AND A. Y. COOPERRIDER. 1994. Saving nature's legacy: Protecting and restoring biodiversity. Island Press and Defenders of Wildlife, Washington, D.C.

NOSS, R. F., E. T. LAROE, III, AND J. M. SCOTT. 1995. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation. United States National Biological Service, Biological Report 28, Washington, D.C.

OLSON, E. C., M. L. BOWMAN, AND R. E. ROTH. 1984. Interpretation and nonformal environmental education in natural resource management. Journal of Environmental Education 15(4):6-10.

ORR, D. W. 1994. Earth in mind: On education, environment, and the human prospect. Island, Covelo, California.

PERDUE, R. R., AND D. S. WARDER. 1981. Environmental education and attitude change. Journal of Environmental Education 12(3):25-28.

POMERANTZ, G. A. 1991. Evaluation of natural resource education materials: Implications for resource management. Journal of Environmental Education 22(2):16-23.

PURDY, K. G., AND D. J. DECKER. 1989. Obtaining wildlife values information for management: The wildlife attitudes and values scale (WAVS). Human Dimensions in Natural Resources Unit, Cornell University, Ithaca, New York.

READING, R. P., T. W. CLARK, AND S. R. KELLERT. 1994. Attitudes and knowledge of people living in the Greater Yellowstone Ecosystem. Society and Natural Resources 7:349-365.

SALANT, P., AND D. A. DILLMAN. 1994. How to conduct your own survey. John Wiley and Sons, New York, New York.

SAS INSTITUTE, INC. 1988. SAS/STAT user's guide, release 6.03 edition. SAS Institute, Cary, North Carolina.

SHRIGLEY, R. L., J. T. R. KOBALLA, AND R. D. SIMPSON. 1988. Defining attitude for science educators. Journal of Research in Science Teaching 25(8):659–678.

SLOCOMBE, D. S. 1993. Implementing ecosystem-based management: Development of theory, practice, and research for planning and managing a region. BioScience 43(9): 612–622.

TAMIR, P. 1991. Factors associated with the relationship between formal, informal, and nonformal science learning. Journal of Environmental Education 22(2):34–42.

UNITED STATES AIR FORCE. 1993. Natural resources management plan, Eglin Air Force Base, Florida. Air Force Development Test Center, Eglin Air Force Base, Florida.

UNITED STATES FISH AND WILDLIFE SERVICE. 1982. 1980 national survey of fishing, hunting, and wildlife associated recreation. United States Fish and Wildlife Service and United States Bureau of the Census, Washington, D.C.

UNITED STATES FISH AND WILDLIFE SERVICE. 1988. 1985 national survey of fishing, hunting, and wildlife associated recreation. United States Fish and Wildlife Service, Washington, D.C.

VAUGHN, S. 1983. Interpreting attitudes, beliefs, and behaviors. Pages 174–181 *in* Proceedings of the 1983 workshop: Advances in interpretation. National Association of Interpreters, West Lafayette, Indiana.

WHITE, T. G., AND S. K. JACOBSON. 1994. Evaluating conservation education programs at a South American zoo. Journal of Environmental Education 25(4):18–22.

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Quantification of submerged wood in a lowland Australian stream system

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SUMMARY

1. The importance of submerged wood (snags) as macroinvertebrate habitat was evaluated in the Pranjip–Creightons Creek system, a lowland stream system in northern Victoria. Snag surface area and biomass were measured at ten sites along the system. The first four upstream sites, located in the foothills of the Strathbogie Ranges, and the next three sites, on the northern Victorian riverine plain, were affected by streambank erosion and high sediment loads and contained little instream wood. A further three sites (Sites 8, 9 and 10) downstream on the riverine plain were not as affected by erosion and possessed extensive stands of riparian river redgum, *Eucalyptus camaldulensis*, which contributed large amounts of wood to the stream channel.
2. Wood quantities at Site 8 were less than at Sites 9 and 10 downstream where the density of riparian redgum was greater. At Sites 9 and 10, snag surface area per m^2 of stream bed was $0.57–0.92\,m^2$ and $0.38–0.71\,m^2$ depending on discharge. Total snag biomass in the stream channel at the same sites was 26 and $41\,kg\,m^{-2}$, respectively. Redgum was important to macroinvertebrates as habitat, at one site contributing 25% of total macroinvertebrate densities and over 30% of total macroinvertebrate biomass m^{-2} of stream bed.
3. Estimations of nitrogen content and C:N ratios of decayed redgum were carried out to provide information on its putative nutritional quality to xylophagous macroinvertebrates. Decayed redgum wood has a comparatively high N content and therefore a low C:N ratio, but appeared to be unpalatable to most macroinvertebrates. Only two macroinvertebrate species, the chironomid larvae *Stenochironomus* sp. and *Dicrotendipes* sp., were found to consume decayed redgum.

Introduction

In rivers and streams world-wide, coarse woody debris is often a key structural habitat component for fish and invertebrates (see Harmon *et al.*, 1986 for an extensive review of the ecological role of coarse woody debris in temperate ecosystems, including streams). In high-gradient forest streams, woody debris jams retain organic matter and create areas of slow-flowing water (Bilby & Likens, 1980). In low-gradient soft-bottomed streams, submerged wood, or snags, are the preferred habitat of many macroinvertebrate species. For example, in sandy-bottomed blackwater streams of the south-eastern U.S.A., snags provide stable surfaces for attachment of filter feeders such as the larvae of caddisflies and blackflies (Benke *et al.*, 1984; Wallace & Benke, 1984). In streams with muddy, anaerobic sediments, snags may also provide a refuge from low levels of dissolved oxygen (O'Connor, 1991a,b). Secondary production of macroinvertebrates on snags in blackwater rivers may be far higher than adjacent sandy or muddy benthic habitats (Benke *et al.*, 1984; Smock, Gilinsky & Stoneburner, 1985). Snags can also provide nesting and spawning sites for fish (e.g. Jackson, 1978), refuges from high water velocities and predators, and

can be an important source of macroinvertebrates for insectivorous fish (Benke *et al.*, 1985).

Submerged wood is abundant in the streams and rivers draining the inland slopes of the Great Dividing Range of south-eastern Australia, and often originates from riparian river redgum, *Eucalyptus camaldulensis*. Mature specimens of redgum are large trees with an open branching habit when growing over water, and a propensity to shed limbs during hot weather and storms. Redgum wood is dense and the sound nature of century-old river wharf pylons suggests that it is slow to decay. A slow decay rate may be a factor contributing to the quantities of submerged wood.

Here estimates of the amount of wood present at ten sites along a lowland stream system in north-central Victoria are presented. The main objectives of this study were: (i) to provide estimates of the surface area and biomass of woody debris, and (ii) to evaluate the significance of snags as a macroinvertebrate habitat and food source.

Materials and Methods

Study sites

The Pranjip–Creightons Creek system is a low-gradient stream system draining the south-western arm of the Strathbogie Ranges of north-central Victoria, Australia. Mean annual discharge of Pranjip Creek is 63 400 Ml, and flow in the creek ceases in summer upstream of its confluence with the perennial Creightons Creek. Downstream of the confluence, flow dwindles to zero in most years before the stream reaches the Goulburn River. Along upstream reaches of the system there has been severe streambank erosion due to bank trampling and overgrazing by sheep and cattle, and much of the original riparian vegetation has been lost. Ten study sites were selected along the system. The first four upstream sites were located in the foothills of the Strathbogie Ranges, and the next six sites were located on the northern Victorian riverine plain (see O'Connor, 1991b, for further details of the study sites).

Estimation of wood volume and surface area

The line-intersect technique of Wallace & Benke (1984) was used to estimate wood volume, surface area, and mean log diameter of snags at each of the ten study sites in the system. Briefly, for a transect of length L, all log diameters, d_i are measured and the information used to calculate the volume of wood per unit area, using the following equation;

$$X_v = (\pi^2/8L)\Sigma d_i^2$$

Wood surface area is calculated as;

$$X_{sa} = (\pi^2/2L)\Sigma d_i^2$$

Note that log lengths do not need to be measured because they cancel out in the initial calculations (see Wallace & Benke, 1984). Twenty transects, randomly spaced over about 1 km (subject to the constraint that the minimum and maximum distances between adjacent transects were 10 and 100 m, respectively), were taken at each site during low summer discharge in February. At Sites 1–7 the diameters of all submerged sticks and logs ≥1 cm in diameter were measured in transects across the stream. At Sites 9 and 10, which had high banks, log diameters were measured at three heights; submerged, 0–1 m above the water surface, and 1–2 m above the surface. No sampling was carried out above this level as 2 m above the water surface at low flow was close to the height of the bank. At Site 8, the top of the bank was only 1 m above the water surface and thus wood measurements for this site were restricted to two categories, submerged, and 0–1 m.

At most sites, twenty transects were enough to achieve 95% confidence intervals for surface area measurements that were generally less than 50% of the mean. Preliminary analysis of the data showed that values for Site 10 had a large error component because wood was patchily distributed due to several large debris jams. To reduce this error component a further twenty-five transects were taken at Site 10 in April when water levels were still low, prior to the commencement of winter rains.

The amount of submerged wood changes with fluctuations in discharge. To estimate the annual variation in the amount of submerged wood at Site 10, the surface area of submerged wood was calculated between mean annual minimum flow, which was close to the rate of discharge when transect measurements were taken, and mean annual peak flow, which was close to bankfull height. Mean annual maximum and minimum flows were calculated from flow records of the Victorian Rural Water Commission's gauging station at Site 10.

Estimation of wood specific gravity and wood mass

At Site 10, samples were collected, using a chainsaw, from sixty logs (2–75 cm diameter) which were either submerged or lying on the bank. In the laboratory the depth of the peripheral discoloured layer of wood was measured and a bandsaw used to take subsamples from it and the interior of each log. When freshly cut from living trees, redgum wood is brick-red. Wood samples that were brick-red were categorized as undecayed and those that had changed to yellow or grey as decayed. Wood subsamples were oven-dried at 60°C for 3 days and weighed. The volume of irregularly shaped subsamples was measured by liquid displacement. The subsamples were then ashed at 550°C for 3 h and reweighed to obtain ash-free dry weight. Wood specific gravity was calculated by dividing ash-free dry weight by subsample volume. Wood mass at each site was calculated as the product of the specific gravity of undecayed wood and wood volume.

Carbon–nitrogen ratios

Carbon and nitrogen contents were measured firstly to derive C–N ratios, and therefore a guide to the nutritional quality of decayed wood to xylophagous macroinvertebrates, and secondly to provide a reliable method of assessing the accuracy of visually determined decay categories. For carbon analyses, 0.05-g portions of finely ground, oven-dried wood were digested in chromic acid, and total carbon content estimated using the rapid titration method (Allen, 1974). For nitrogen analyses, 0.5-g portions of finely ground, oven-dried wood were digested in concentrated sulphuric acid, and nitrogen content measured using a Kjeltec Auto 1030 Nitrogen Analyser.

Macroinvertebrates

Ten replicate samples each of snags and the benthos were taken at Site 10 during the low-flow period on 28 March. Snag samples were collected by placing a 250-μm mesh net around a snag and cutting off a 30-cm section with a pruning saw. Benthic samples were collected with a suction sampler (Boulton, 1985) modified to sample soft sediments. Further details of the sampling procedure of these two treatments are described in O'Connor (1991a). After identification and counting, densities of all taxa were converted to numbers m^{-2} and biomass m^{-2} of substrate surface. Biomass was estimated from length–weight regressions cited in Smock (1980) for aquatic insects, and Rosen (1981) for microcrustaceans. Measurements of biomass of preserved and dried specimens were taken of larger crustaceans (e.g. *Paratya australiensis*) and annelids (e.g. *Branchiura sowerbyi*).

Results

Wood distribution

There was less wood at Sites 1–7 than sites further downstream (Fig. 1). Slight increases in wood volume at Sites 4 and 7 were caused by solitary large logs. Large amounts of sand derived from erosion in the upper catchment have affected stream morphology at Sites 1–7 (O'Connor, 1991b). At these sites, overgrazing of riparian vegetation and trampling by livestock have caused the streambank to collapse, taking with it riparian trees. Most fallen trees have either been covered with sand or, less commonly, removed in stream management works. Site 2 was an exception among sandy sites in possessing a significant stand of riparian redgum; nevertheless, there was little wood present in the stream. Any wood falling into the stream at this site may have been rapidly smothered in sand. Wood quantities at Site 8 were also relatively low, possibly because transect measurements were taken through a long swampy section where the density of riparian redgum was lower than downstream.

In contrast to sites upstream, Sites 9 and 10 had large amounts of wood in the main channel and on the banks (Fig. 1, Table 1). At these sites there were large mature redgums growing from the low-flow water level up to and over the stream bank. Many of these living trees had large portions of their root systems exposed, some of which were greater than 5 m in diameter. Exposed roots contributed significantly to the total surface area of wood available for macroinvertebrate colonization at higher discharges. The bulk of wood that was not submerged at low flow lay on the stream banks rather than suspended over the stream. Of the total amount of wood in the stream, most lay submerged at low flow with decreasing amounts at higher elevations (Table 1).

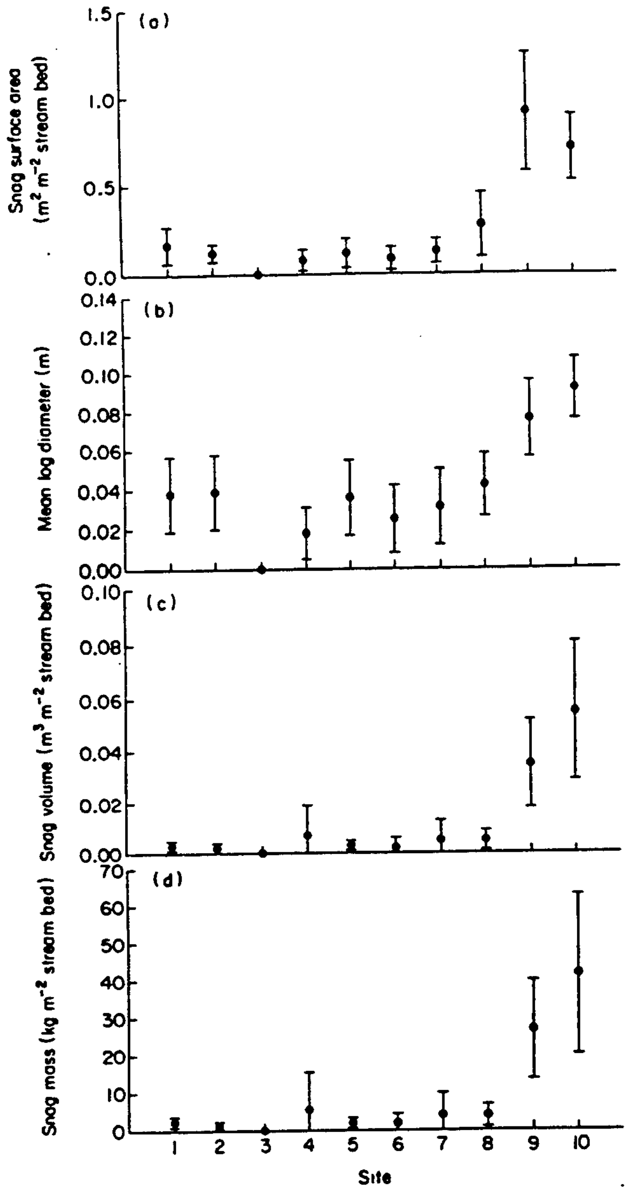

Fig. 1 (a) Snag surface area, (b) mean diameter, (c) snag volume, and (d) snag mass for each study site along the Pranjip–Creightons Creek system (±95% CI). Mean log diameters and wood surface area appear high at Site 8, despite low volume, because only submerged wood values were used for Sites 8, 9 and 10 in (b).

Wood surface area and discharge

At bankfull stream height, snags constituted 21, 47, and 41% of the total surface area available for macroinvertebrate colonization at Sites 8, 9 and 10, respectively. At low water these values dropped to 15, 30 and 28%, respectively. During the 6-month high-flow period (May–October), the contribution of snags to the total wetted surface area of the stream at Site 10 remained between 38 and 41%. This indicated that snags were approximately evenly distributed at higher elevations at the site despite a significant ($P < 0.05$) but small decrease in the surface area of logs at increasing elevations (Table 1). During the high-flow period, when discharge is consistently greater than 125 Ml day^{-1}, the water level was between 1 and 2 m above the low-flow surface level (Fig. 2). During the 6-month low-flow period (November–April), snags constituted between 28 and 38% of the total wetted surface area.

Wood specific gravity, biomass and C:N ratios

The mean specific gravity of undecayed redgum was 0.75 g cm^{-3}, and was significantly higher in logs greater than 10 cm in diameter compared to logs less than or equal to 10 cm in diameter (pooled variances $t = 2.798$, df = 58, $P = 0.007$; Table 2). Decayed wood was limited to the periphery of logs [mean depth of decay = 5 ± 2 mm, (95% CI) $n = 60$]. Large logs supported a deeper decayed layer than small logs (regression of decay depth v log diameter, $r^2 = 0.313$, $F = 25.94$, df = 1, 57, $P < 0.001$) possibly because large logs were resistant to fracture due to sagging under

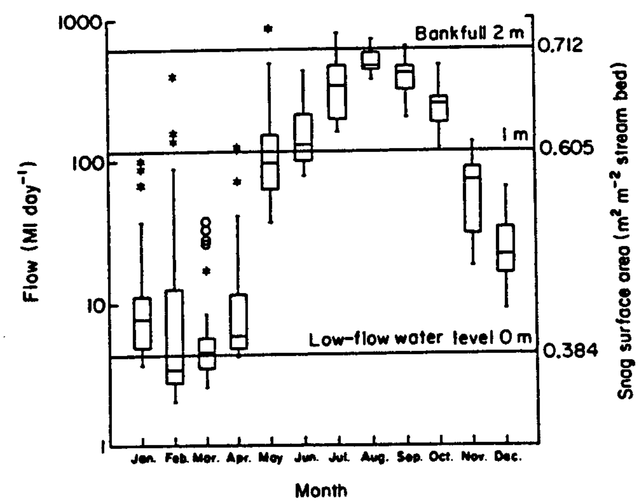

Fig. 2 Box plot of monthly means of mean daily flow for Site 10 with estimated surface area of submerged snags scaled alongside (23 years of data, from 1 January 1956 to 30 April 1988). Each box encloses the upper and lower fourth spread (fourth spread = mean − 0.6745 × standard deviation). The central bar on each box is the median. Outlying values are greater in magnitude than 1.5 fourths–denoted by the lines extending from each box. *, outlier; o, extreme outlier.

Table 1 Wood surface area, mean log diameter, volume and mass (±95% confidence intervals) for submerged wood, and at heights 0–1 and 1–2 m above the water surface at Sites 8, 9 and 10 in the Pranjip–Creightons Creek system. For Sites 8 and 9, $n = 20$, for Site 10, $n = 45$

	Site	Submerged	1 m	2 m
Surface area ($m^2 m^{-2}$)	8	0.176 ± 0.088	0.099 ± 0.093	–
	9	0.571 ± 0.244	0.272 ± 0.072*	0.073 ± 0.023
	10	0.384 ± 0.074*	0.221 ± 0.060*	0.107 ± 0.052
Mean log diameter (m)	8	0.042 ± 0.016	0.026 ± 0.016	–
	9	0.076 ± 0.020	0.058 ± 0.018	0.065 ± 0.038
	10	0.092 ± 0.016	0.090 ± 0.020	0.110 ± 0.038
Volume ($m^3 m^{-2}$)	8	0.004 ± 0.002	0.001 ± 0.002	–
	9	0.019 ± 0.009	0.010 ± 0.004	0.006 ± 0.004
Mass ($kg\,m^2$)	10	0.030 ± 0.012	0.015 ± 0.008	0.010 ± 0.006
	8	2.9 ± 2.0	1.0 ± 0.9	–
	9	14.2 ± 6.4	7.7 ± 3.4	4.8 ± 3.4
	10	22.7 ± 9.7	11.2 ± 6.5	7.5 ± 5.2

* Significant difference among adjacent heights (adjusted probability $P < 0.025$); independent samples t-test between submerged and 0–1 m above low-flow water surface, paired sample t-test between 0–1 m and 1–2 m above.

Table 2 Specific gravity, % carbon, % nitrogen and the C:N ratio of undecayed inner wood and decayed outer wood of logs ≤10 cm in diameter, logs >10 cm in diameter, and mean value ($\bar{x}$) for all logs (±95% confidence intervals). For $\bar{x}$, $n = 60$; for logs ≤10 cm diameter, $n = 37$; for logs >10 cm diameter, $n = 23$

	Undecayed			Decayed		
	≤10 cm	>10 cm	$\bar{x}$	≤10 cm	>10 cm	$\bar{x}$
Specific gravity	0.72 ± 0.03	0.78 ± 0.14	0.75 ± 0.01	0.37 ± 0.07	0.50 ± 0.04	0.43 ± 0.06
% Carbon	46.0 ± 0.7	44.3 ± 1.7	45.3 ± 0.4	41.2 ± 1.01	40.0 ± 2.3	40.8 ± 1.2
% Nitrogen	0.12 ± 0.02	0.09 ± 0.02	0.11 ± 0.01	0.47 ± 0.07	0.70 ± 0.14	0.56 ± 0.8
C:N ratio	466 ± 56	566 ± 58	492 ± 29	111 ± 17	79 ± 25	99 ± 16

their own weight. The mean specific gravity of the peripheral decayed layer was $0.43\,g\,cm^{-3}$, and was also significantly higher in logs greater than 10 cm in diameter compared to logs 10 cm in diameter or less (separate variances $t = -2.163$, df = 51, $P = 0.035$).

The thinness of the decayed layer on most logs meant that most wood present in the stream was undecayed. Thus the mean specific gravity of undecayed wood was used calculate wood mass at each site. Little wood was present at sites upstream of Site 9 (Fig. 1, Table 1). The classification of discoloured redgum wood as decayed was supported by the large difference in C:N ratios between decayed (i.e. discoloured) and undecayed (i.e. brick-red) wood (independent samples t-test, pooled variances $t = 12.82$, df = 118, $P < 0.001$. Table 2).

Macroinvertebrates

In terms of both densities and biomass, the macroinvertebrate fauna at Site 10 was dominated by collector–gatherer species. The most numerous species on snags were naidid oligochaetes, while on the stream bed larvae of the chironomid, *Polypedilum tonnoiri*, were the most abundant (Table 3). Standing-stock biomass on snags was dominated by the large atyid shrimp *Paratya australiensis*. *P. australiensis* was absent from benthos, in which *P. tonnoiri*, tubificid oligochaetes, and nematodes were the most important contributors to standing-stock biomass (Table 3).

During low autumn flow, when macroinvertebrate samples were collected, the surface area of submerged wood at Site 10 was $0.384\,m^2$ per m^2 stream

Table 3 Densities and biomass (±95% confidence intervals, $n = 10$) of the fifteen most abundant snag and benthic macroinvertebrates (in terms of biomass) at Site 10 on the Pranjip–Creightons Creek system. The abbreviation after each taxon refers to the following taxonomic information. Crustacea: C., Cladocera; C.Ma, Macrothricidae; C.Ch, Chydoridae; Co.Cy, Copepoda, Cyclopoida; Os, Ostracoda; Os.Cy, Cypridae; Os.Ca, Candonidae; De.At, Decapoda, Atyidae. Insecta: D.Ch, Diptera, Chironomidae. Annelida: Ol, Oligochaeta; Ol.Na, Naididae; Ol.Tu, Tubificidae; Ol.Lu, Lumbricidae. Nematoda: Ne., Nematoda. The total includes less abundant species (in terms of biomass) which are not shown here

Taxon		Snags		Benthos	
		Numbers m^{-2}	Biomass $mg\,m^{-2}$	Numbers m^{-2}	Biomass $mg\,m^{-2}$
Ilyocryptus sp.	C.Ma	11 ± 11	0.20 ± 2.08	14 ± 16	0.34 ± 0.25
Leydigia sp.	C.Ch	26 ± 45	0.24 ± 0.36	4 ± 4	0.49 ± 0.04
Alona sp.	C.Ch	20 ± 18	0.19 ± 0.20	5 ± 7	0.06 ± 0.09
Camptocercus australis Sars	C.Ch	16 ± 13	0.20 ± 0.20	15 ± 9	0.21 ± 0.11
Acanthocyclops robustus (Sars)	Co.Cy	137 ± 70	2.33 ± 1.08	34 ± 36	0.75 ± 0.81
Ilyocypris australiensis Sars	Os.Cy	22 ± 36	0.22 ± 0.36	98 ± 43	1.35 ± 0.59
Candonocypris sp.	Os.Ca	1 ± 2	0.02 ± 0.04	18 ± 11	0.36 ± 0.25
Paratya australiensis Kemp	De.At	11 ± 11	1139.79 ± 268.30	0 ± 0	0.00 ± 0.00
Polypedilum tonnoiri Freeman	D.Ch	44 ± 22	19.16 ± 10.65	902 ± 303	453.25 ± 152.77
Cladopelma curtivalva Kieffer	D.Ch	7 ± 7	0.84 ± 0.75	47 ± 25	6.81 ± 3.53
Naididae spp.	Ol.Na	498 ± 448	58.15 ± 57.00	41 ± 25	4.61 ± 2.92
Tubificidae spp.	Ol.Tu	18 ± 38	21.80 ± 45.92	181 ± 52	316.75 ± 89.57
Lumbriculus variegatus Müller	Ol.Lu	22 ± 45	3.74 ± 5.77	32 ± 25	100.01 ± 82.15
Branchiura sowerbyi Beddard	Ol.Tu	4 ± 9	95.37 ± 192.50	16 ± 13	200.00 ± 162.98
Nematoda spp.	Ne.	8 ± 11	17.17 ± 40.03	54 ± 45	2.00 ± 4.52
Total		3086 ± 771	1635 ± 463	3932 ± 371	1131 ± 93

bed. Multiplying this value by the total density of snag macroinvertebrates per m^2 of snag surface (from Table 3) gives an estimate of 1185 ± 809 (95% CI) snag macroinvertebrates per m^2 of stream bed, about 25% of the total (i.e. snag plus benthos). Total biomass of snag macroinvertebrates was 0.63 ± 0.45 (95% CI) g per m^2 of stream bed, just over 30% of the total. If similar or higher macroinvertebrate densities and biomass occur on snags during high winter–spring flows then the contribution of the snag fauna to the total numbers and biomass per m^2 of stream bed will be proportionally higher.

Discussion

Total snag surface area per m^2 of stream bed at downstream sites in the Pranjip–Creightons Creek system was up to 2.1 times greater than that found by Wallace & Benke (1984) in two blackwater streams in Georgia, U.S.A. This was due to the greater wood volumes and mean log diameters rather than an abundance of small logs with their concomitant high surface area to volume ratios.

Absence of riparian vegetation and changes in channel morphology were associated with lower amounts of submerged wood at sites upstream of Site 9 (O'Connor, 1991b). However, the smaller amounts of wood present may still significantly contribute to macroinvertebrate habitat. For example, snag surface area estimates at Sites 1–8 were between 0.1 and 0.25 m^2 per m^2 of stream bed, only slightly less than those for the blackwater streams where Wallace & Benke (1984) considered snags a significant macroinvertebrate habitat.

Total wood volumes per square metre of stream bed at Sites 9 and 10 were between 2 and 3.7 times greater than those found by Wallace & Benke in the Ogeechee River and Black Creek, Georgia. However, because of the high specific gravity of redgum, wood biomass estimates, which reached 41.1 $kg\,m^{-2}$ at site 10 on Pranjip Creek, were between 5.3 and 8.2 times those of the Ogeechee River and Black Creek.

Although higher estimates of wood biomass than that found in the present study have been recorded for small high-gradient stream [e.g. 180 $kg\,m^{-2}$ for redwood forest streams in California (Keller *et al.*, 1985, cited in Harmon *et al.*, 1986)], most wood in such streams hangs suspended over the stream channel

and does not act directly as habitat for aquatic macroinvertebrates (Robison & Beschta, 1990). For larger rivers there are no quantitative studies of wood, but it appears that the presence of large amounts of coarse woody debris is characteristic of large rivers in their natural state (Sedell & Froggatt 1984; Triska 1984; Harmon *et al.*, 1986; Sedell *et al.*, 1990; Walker, Thoms & Sheldon, 1991).

Wood decay

Decay of submerged redgum logs was limited to the surface few millimetres of wood. Peripheral decay is commonly found in submerged logs as waterlogging limits the depth of penetration of dissolved oxygen and therefore aerobic, decay-causing bacteria and fungi (Van Coillie *et al.*, 1983; Aumen *et al.*, 1983; Harmon *et al.*, 1986). In addition, the density of redgum wood is relatively high and so the depth of oxygen penetration, and therefore decay rate, may be less than for other types of wood. At Sites 8, 9 and 10, which had muddy bottoms rich in organic matter, low oxygen levels in the surrounding mud and water (as evidenced by the unmistakable smell of hydrogen sulphide) may slow decay rates even further. Because decay is slow, a thick layer of decayed wood never develops around submerged logs. Instead decayed wood particles are probably abraded from the surface of the log long before deeper layers of wood begin to decay. Ward & Aumen (1986) found erosion rates of wood varied from between 0.5 and 11 mm per year in an Oregon stream, depending on the state of decay of the log. Despite limitations in oxygen diffusion, the decay rate of submerged logs may increase exponentially as cracks and splits in the wood eventually deliver some oxygen to deeper layers.

The C:N ratio of undecayed redgum wood [492 ± 58 (95% CI)] was similar to that reported for red alder, *Alnus rubra*, by Baker, Morita & Anderson (1983). In Oregon streams, alder wood decays faster than the coniferous Douglas fir, *Pseudotsuga menziesii* (Anderson *et al.*, 1978; Baker *et al.*, 1983), which has a relatively high C:N ratio of 1100 (Anderson *et al.*, 1978; Buckley & Triska, 1978; Baker *et al.*, 1983). The low N content of Douglas fir (about 0.04%, Anderson *et al.*, 1978) may be one reason why it is slow to decay. Aumen *et al.* (1983) found that decay rates of laboratory-incubated samples of Douglas fir wood increased when inorganic nitrates were added. The C:N ratio of wood decreases during decay due to the fixation of N by fungi and bacteria and the loss of C through respiration and leaching (Triska & Cromack, 1980). Baker *et al.* (1983) found the decay rate of alder due to microbial activity to be about four times that of Douglas fir. They attributed this to the enhanced N fixation by bacteria on alder rather than inhibition of microbial activity by the high amounts of tannins in Douglas fir wood. Nevertheless, other classes of wood extractives (e.g. terpines) do inhibit microbial activity (Scheffer & Cowling, 1966).

As microbial biomass increases in decaying wood, as measured by the decreasing C:N ratio, its palatability to macroinvertebrates increases. In Oregon streams the larvae of several species of Diptera preferred decayed alder wood to undecayed wood (Dudley & Anderson, 1987; Anderson, 1989). Macroinvertebrate feeding activities may also speed up the decay process, through direct wood consumption by wood eaters and incidental surface scouring by periphyton grazers. Anderson *et al.* (1978) attributed the rapid surface decay of alder wood blocks in an Oregon stream to the feeding activities of the entire macroinvertebrate complex, particularly snails.

Despite its relatively high N content, only two species of xylophagous macroinvertebrates were found in decayed redgum, the chironomid dipteran larvae *Stenochironomus* sp. (National Museum of Victoria voucher NMV3) and *Dicrotendipes* sp. (NMV30)—guts of both species were always packed with wood fragments. Furthermore, in comparison to many other snag-dwelling species (see below), neither were particularly abundant on snags.

One reason why redgum wood, despite its apparently high nutritional value, is not widely used as a food source by macroinvertebrates may be that the high nitrogen content of decayed redgum is not in a digestible form. For example, the structural component of fungal cell walls, chitin, is a chemically complex polymer that may be difficult to break down (Odum, Kirk & Zieman, 1979). Alternatively, tannins and other extractives in redgum wood may inhibit macroinvertebrate feeding.

Submerged wood as macroinvertebrate habitat

Total macroinvertebrate densities and dry biomass on snags at Site 10 in the Pranjip–Creightons Creek system were only 7 and 25%, respectively, of that of

snags in Ogeechee River, Georgia (Wallace & Benke, 1984). The reason for such a large difference between the two studies is unclear, but it may be due to a lower nutritional value and rate of supply of suspended particulate organic matter in the Pranjip–Creightons Creek system. The snag fauna of the Ogeechee and other south-eastern United States blackwater streams is dominated by filter-feeding hydropsychid caddisfly larvae and simuliid blackfly larvae (Wallace & Benke, 1984; Benke *et al.*, 1984; Smock *et al.*, 1985), whereas collector–gathering macroinvertebrates dominated the snag fauna at Site 10. Both hydropsychids and simuliids were common in sandy benthic habitats at upstream sites (e.g. Sites 5 and 6) on the Pranjip–Creightons Creek system, but rare (simuliids) or absent (hydropsychids) on snags at Site 10. Flow at Sites 8, 9, and 10 is intermittent (see O'Connor, 1991b), thus when flow ceases, these sites become unsuitable for passive filter-feeding macroinvertebrates such as simuliids and hydropsychids. In winter and spring, when the stream is flowing, turbidities and concentrations of suspended fine particles are high and horizontal surfaces are coated with a thick layer of sediment (O'Connor, 1991a). Such conditions are also unlikely to suit filter-feeding insects which are probably an important component of the snag fauna only in perennial streams with relatively low turbidity.

During high flows, snags constitute up to 47% of the total surface area available for macroinvertebrate colonization in Pranjip Creek. Although in comparison to the benthos, snags were poorer in numbers of individuals per unit area, in terms of biomass they were richer than the benthos. When macroinvertebrate densities on snags were expressed as densities per unit area of stream bed, they made up about 33% of the total number of macroinvertebrates present. In terms of biomass, this value was about 50%. Qualitative differences in the physicochemical characteristics of the two habitats (e.g. low levels of dissolved oxygen in benthic mud) may be responsible for the differences.

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References

Allen S.E. (1974) *Chemical Analysis of Ecological Materials*. Blackwell Scientific Publications Ltd, Oxford, U.K.

Anderson N.H. (1989) Xylophagous Chironomidae from Oregon streams. *Aquatic Insects*, **11**, 33–45.

Anderson N.H., Sedell J.R., Roberts L.M. & Triska F.J. (1978) The role of aquatic invertebrates in processing of wood debris in coniferous forest streams. *American Midland Naturalist*, **100**, 64–82.

Aumen N.G., Bottomley P.J., Ward G.M. & Gregory S.V. (1983) Microbial decomposition of wood in streams: distribution of microflora and factors affecting [^{14}C] lignocellulose mineralization. *Applied and Environmental Microbiology*, **46**, 1409–1416.

Baker J.H., Morita R.Y. & Anderson N.H. (1983) Bacterial activity associated with the decomposition of woody substrates in a stream sediment. *Applied and Environmental Microbiology*, **45**, 516–521.

Benke A.C., Van Arsdall T.C., Gillespie D.M. & Parrish F.K. (1984) Invertebrate productivity in a subtropical blackwater river: the importance of habitat and life history. *Ecological Monographs*, **54**, 25–63.

Benkey A.C., Henry R.L. III, Gillespie D.M. & Hunter R.J. (1985) Importance of snag habitat for animal production in Southeastern streams. *Fisheries*, **10**, 8–13.

Bilby R.E. & Likens G.E. (1980) Importance of organic debris dams in the structure and function of stream ecosystems. *Ecology*, **61**, 1107–1113.

Boulton A.J. (1985) A sampling device that quantitatively collects benthos in flowing or standing waters. *Hydrobiologia*, **127**, 31–39.

Buckley B.M. & Triska F.J. (1978) Presence and ecological role of nitrogen-fixing bacteria associated with wood decay in streams. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie*, **20**, 1333–1339.

Dudley T.L. & Anderson N.H. (1987) The biology and life cycles of *Lipsothrix* spp. (Diptera: Tipulidae) inhabiting wood in western Oregon streams. *Freshwater Biology*, **17**, 437–451.

Harmon M.E., Franklin J.F., Swanson F.J., Sollins P., Gregory S.V., Lattin J.D., Anderson N.H., Cline S.P., Aumen N.G., Sedell J.R., Lienkaemper G.W., Cromack K. & Cummins K.W. (1986) Ecology of coarse woody debris in temperate ecosystems. *Advances in Ecological Research*, **15**, 133–302.

Jackson P.D. (1978) Spawning and early development of the river blackfish, *Gadopsis marmoratus* Richardson (Gadopsiformes: Gadopsidae), in the McKenzie River, Victoria. *Australian Journal of Marine and Freshwater Research*, **29**, 293–298.

O'Connor N.A. (1991a) The effects of habitat complexity

on the macroinvertebrates colonising wood substrates in a lowland stream. *Oecologia*, **85**, 504–512.

O'Connor N.A. (1991b) *The ecology of a northern Victorian lowland stream system*. Ph.D. Thesis, Department of Ecology & Evolutionary Biology, Monash University, Clayton, Victoria, Australia.

Odum W.E., Kirk P.W. & Zieman J.C. (1979) Non-protein nitrogen compounds associated with particles of vascular plant detritus. *Oikos*, **32**, 363–367.

Robison E.G., & Beschta R.L. (1990) Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA. *Canadian Journal of Fisheries and Aquatic Sciences*, **47**, 1684–1693.

Rosen R.A. (1981) Length-dry weight relationships of some freshwater zooplankton. *Journal of Freshwater Ecology*, **1**, 225–229.

Scheffer T.C. & Cowling E.B. (1966) Natural resistance of wood to microbial deterioration. *Annual Review of Phytopathology*, **4**, 147–170.

Sedell J.R., Reeves G.H., Hauer F.R., Stanford J.A. & Hawkins C.P. (1990) Role of refugia in recovery from disturbances: modern fragmented and disconnected river system. *Environmental Management*, **14**, 711–724.

Sedell J.R. & Froggatt J.L. (1984) Importance of streamside forests to large rivers: the isolation of the Willamette River, Oregon, U.S.A., from its floodplain by snagging and streamside forest removal. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie*, **22**, 1828–1834.

Smock L.A., Gilinsky E. & Stoneburner D.L. (1985) Macroinvertebrate production in a southeastern United States blackwater stream. *Ecology*, **66**, 1491–1503.

Smock L.A. (1980) Relationships between body size and biomass of aquatic insects. *Freshwater Biology*, **10**, 375–383.

Triska F.J. (1984) Role of wood debris in modifying channel geomorphology and riparian areas of a large lowland river under pristine conditions: a historical case study. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie*, **22**, 1876–1892.

Triska F.J. & Cromack K.C. Jr (1980) The role of wood debris in forests and streams. *Forests: Fresh Perspectives from Ecosystem Analysis* (Ed. R.H. Waring), pp. 171–190. Oregon State University Press, Corvallis, Oregon, USA.

Van Coillie R., Visser S.A., Campbell P.G.C. & Jones H.G. (1983) Evaluation de la dégradation du bois de conifères immergés durant plus d'un demi-siècle dans un résevoir. *Annales de Limnologie*, **19**, 129–134.

Walker K.F., Thoms M.C., Sheldon F. (1991) The effects of weirs on the littoral environment of the River Murray, South Australia. *River Conservation and Management* (Eds P.J. Boon, G.E. Petts and P. Calow). Wiley, Chichester, U.K. (in press).

Wallace J.B. & Benke A.C. (1984) Quantification of wood habitat in subtropical coastal plain streams. *Canadian Journal of Fisheries and Aquatic Sciences*, **41**, 1643–1652.

Ward G.M. & Aumen N.G. (1986) Woody debris as a source of fine particulate organic matter in coniferous forest stream ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences*, **43**, 1635–1642.

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Woody debris, forest-stream succession, and catchment geomorphology

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Abstract. The retention potential of forested headwater streams is strongly influenced by forest succession through the input and transport of different amounts and types of wood and the interaction of woody debris with drainage basin geomorphology during forest succession. To evaluate experimentally the effects of changing amounts of wood on the retention potential of streams, ten log dams were added to a 50-m reach on two second-order streams, Aspen 1 and Aspen 2. Both streams lacked woody debris and flowed through a successional aspen forest in the southern Rocky Mountains. All wood >5 cm in diameter was removed from a 50-m reach of a third stream, Conifer, previously choked with wood in an adjacent climax conifer forest. Although both aspen streams were in the same forest type, Aspen 1 appeared to be at an earlier successional stage than Aspen 2. It flooded more frequently, had more erosion in its upper drainage basin, and had an unstable channel compared with Aspen 2. Within each stream, reaches with wood stored twice the organic matter of reaches without wood. Sides of streams stored more than centers (Aspen 1 = 6×, Aspen 2 = 2×, Conifer = 3.5×). Conifer contained 3.5 times and Aspen 2 contained 2 times more stored organic matter than Aspen 1. Average water velocities were lower in reaches with wood than in reaches without wood in Aspen 2 and Conifer, but not in Aspen 1. Velocities decreased and width and depth increased in both aspen reaches with wood. Velocities increased and width and depth decreased in the conifer reach without wood. Dye-measured transit time revealed the greatest difference between Conifer reaches and the smallest differences between Aspen 1 reaches. Experimental releases of uniformly shaped "woodchips" and spray-painted leaves showed that Aspen 1 was least retentive and Conifer was most retentive, but the greatest difference in retention of particles was between the Aspen 1 reaches.

When wood is added, streams retain and store organic matter directly by holding back organic matter and indirectly by increasing the physical heterogeneity of the channel and deflecting water movement into eddies and backwaters. Finally, the effects of woody debris vary with channel stability supporting the concept of linkage between stream succession and the geomorphic processes occurring within each catchment as a whole.

Key words: Woody debris, succession, geomorphology, retention, land-water interaction, organic matter, stream morphology, riparian, stream ecosystem.

One of the most important contributions of forests to streams is the addition of large wood (Vannote et al. 1980, Likens and Bilby 1982, Hedin et al. 1988). Streams with woody debris generally retain particulate organic matter more efficiently than streams without wood (Bilby and Likens 1980, Bilby 1981, Speaker et al. 1984, Speaker 1985, Golladay et al. 1987, Webster et al. 1988; but see Leff and McArthur 1988). Longer retention times lead to greater storage and processing of large organic particles (Swanson et al. 1982, Harmon et al. 1986). Wood changes stream morphology and creates depositional areas for storage and processing and can itself serve as habitat (Nilson and Larimore 1973, Keller and Swanson 1979, Keller and Tally 1979, Benke et al. 1985, Sedell et al. 1988). Wood interacts with drainage basin geomorphology. Triska et al. (1982) showed that logs have different effects on retention and storage of organic matter depending on changes in seasonal discharge rates. Heede (1972) showed that logs stabilized the gravel beds of mountain streams to create energy-dissipating steps within the stream.

Molles (1982) found that headwater streams draining successional aspen forests in the southern Rockies lacked wood, had lower standing stocks of organic matter, and supported few leaf-shredding insects. Streams in climax conifer forests had many debris dams, a very high standing stock of organic matter, and supported higher densities of shredders. Molles suggested that the addition of wood to a stream late in forest succession was responsible for an increase in detrital storage, which provides both

habitat and food for shredding detritivores in the invertebrate community. If there is little wood in streams, allochthonous detritus may be inefficiently retained as a substantial component of the food base for stream communities, even though it was being added to the stream.

purpose - Measure retention

The purpose of this study was to test whether the amount of wood in a stream could alter retention and storage of organic matter independently of the surrounding forest. Retention is used here to describe the stopping of particles at they move through a stream reach; storage is longer-term incorporation into the stream channel. Several studies have demonstrated differences in particle retention in streams with and without wood (Bilby and Likens 1980, Bilby 1981, Speaker et al. 1984, and Speaker 1985). Speaker et al. (1984) and Speaker (1985) showed that leaf retention efficiencies and causes were different in streams flowing in different forest types. Efficiencies were poor in streams moving through clearcut areas or alder stands and were good in streams flowing through old growth stands. Young et al. (1978) showed that leaves of different sizes and shapes traveled at different speeds in a single stream. Webster et al. (1987) showed that channel roughness increased the amount of seston retained in laboratory streams. The present field study examines dye measured transit time of water, channel morphology, resultant particle travel patterns, obstacles to travel, and long-term organic matter storage to determine how the addition of wood during forest succession changes stream ecosystem function. The following predictions were tested:

1. The addition of dams to successional aspen streams should increase organic matter retention and storage by stopping more particles and increasing the overall physical heterogeneity of the stream.

2. The removal of wood from the climax conifer stream should decrease organic matter retention and storage by eliminating obstacles that stop particles and decreasing the physical heterogeneity of the stream.

Study Site

The three study streams are in the Tesuque Creek Catchment, 15 km northeast of Santa Fe, New Mexico, USA, in the Sangre de Cristo Range of the Rocky Mountains (Fig. 1) and are oriented north-south. Seasonal precipitation is bimodal, and both precipitation and stream discharge vary substantially within and between years (Gosz 1975). Much of this variance is accounted by the El Niño/La Niña Southern Oscillation effect on precipitation in New Mexico (Molles and Dahm 1990). In winter, Pacific moisture dominates and provides 30% of the yearly precipitation as snow. In summer moisture from the Gulf of Mexico dominates and sudden, late-summer thunderstorms provide 70% of the yearly total. Peak flows occur in May during spring runoff and in July and August during thunderstorms. Low flows occur November through February under ice and in late June or early July before recharge from thunderstorms (USGS 1973).

In 1886 a forest fire burned the climax forest of Engleman spruce (*Picea engelmanii*) and corkbark fir (*Abies lasiocarpa* var. *arizonica*; Gosz 1975). After the fire, trembling aspen (*Populus tremuloides*) present in the pre-fire understory, was released in a successional sequence typical of the southern Rocky Mountains. The three study streams are second-order, approximately west-facing, perennial, and spring-fed. All study sites are about 3100 m in elevation. Although Aspen 1 and Aspen 2 both flow through the 100-year-old successional aspen forest created by the 1886 fire, each stream has different amounts of upper basin erosion, different recent flooding histories, morphologies, and biotic communities (Molles 1985). The third stream, Conifer, flows through an adjacent unburned spruce-fir forest. The constrained floodplains of all three streams consist of an unsorted jumble of different rock sizes—evidence that at some time in their geologic history there were debris torrents in the channels (S. Gregory, Oregon State University, personal observation). These debris torrents predate the 1886 fire. In the Conifer drainage, trees as old as 250 years are growing on this rocky floodplain.

Stream and catchment characterization

Data on similarities and differences among the three streams and their catchments were collected during a pre-experimental year to determine interactions between the manipulation of wood and the geomorphic template on which the experiment was imposed (Table 1). Average width and depth (m) and water velocity (m/s)

were based on 26 random measurements/reach. Water velocity was measured with a Weather Measure current flow meter in the thalweg (line of maximum velocity in the channel). Drainage basin areas were estimated from aerial photographs. Average annual discharge was based on water years 1962–1973 (USGS 1973) since all gauging weirs were abandoned after 1973. The nearest gauging weir for the two aspen streams was about 100 m below their confluence. Since the average discharge measured during this study on these two streams was about the same, their average annual discharge was estimated by dividing the USGS data for their confluence by two. In summer, when aspens were in full leaf, light reaching the center of the stream was recorded on one day at mid-day with a Gossen 6 incident light meter (n = 20 random positions/stream). Chlorophyll-*a* concentration was determined by selecting 10 rocks of similar size from each reach, tracing their exposed surfaces, and then soaking them in acetone to extract chlorophyll-*a*, which was read on a spectrophotometer (Parsons et al. 1984).

Streams were ranked for stability (Table 2) using criteria appropriate for these streams (Pfankuch 1975). These included vegetative cover in the catchments, bank erosion and deposition, and large obstructions incorporated into the bank. Criteria for ranking stream bottom stability included consolidation, percentage of stable materials in the channel, and presence or absence of aquatic plants and algae. Scour and lack of colonization by algae were indicated by the brightness of the substrate. Aspen 1 had flash floods in 1977 and 1982. The 1977 flood removed a vertical meter of stream bed and the V-notched weir below both Aspen study sites was destroyed. Stream-insect biomass and relative abundance were severely altered immediately after the flood but recovered rapidly (Molles 1985). After the 1982 flood, the Aspen 1 stream channel consisted of bright, angular gravel. No wood, algae, or moss were visible in the channel or along stream margins. Aerial photos from 1958 and 1965 showed that although the study areas were surrounded by a successional aspen forest, the upper drainage basins of each stream differed considerably in slope, amount of bare ground absorbing heat, and active erosion. The upper catchment of Aspen 1 is heavily eroded (25%), narrow, receives high insolation from the southwest, and lacks

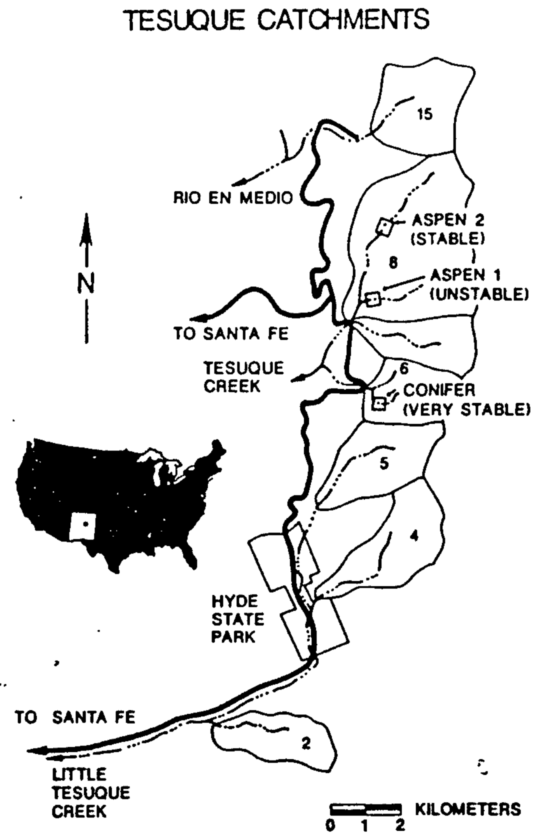

FIG. 1. The Tesuque Catchment Area in the Sangre de Cristo Mountains, New Mexico. Study areas consisting of two 50-m reaches separated by a 25-m buffer are within boxes. Dotted and dashed lines indicate perennial streams; solid lines show catchment boundaries.

downed timber to break the overland flow of water and to store snow for slow spring release. There is little reinvasion by spruce and fir into sparse subalpine grassland of this basin.

Aspen 2 channel was ranked as stable because its channel contained well-established rock bars approximately 2 m apart, creating a series of pools and riffles. The streambed is primarily cobble darkened by attached algae. Moss grows on the stream margins. There are no signs of channel modification such as the gouged banks, exposed plant roots, and bright channel bottom of Aspen 1. Only 5% of the upper slopes of the Aspen 2 drainage is eroded. Although this basin is also southwest-facing, slopes are less steep, there is less bare ground, and more downed timber than in Aspen 1. Aspen 2 contained ap-

TABLE 1. Aspen 1, Aspen 2, and Conifer streams in the Tesuque Catchment Area, Sangre de Cristo Mountains, New Mexico. Means with different superscripts (a, b) are significantly different ($p < 0.01$, Kruskal-Wallace Test and non-parametric multiple comparisons test with Bonferroni correction; Zar 1984). Annual discharge was based on USGS gauging information 1966–1972 (USGS 1973). Algae and moss abundances were estimated visually. CPOM = coarse particulate organic matter (>1 mm); FPOM = fine particulate organic matter (<1 mm). AFDM = ash free dry mass.

-	Aspen 1	Aspen 2	Conifer
Catchment area (ha)	190	225	122
Channel slope	11°, 10°*	10°	10°
Substrata	angular gravel	cobble, organic matter	cobble, sand, organic matter
Rock bars/10 m	0	5	5
Pools/10 m	0.4	1	5
Log dams/10 m	0	1	5
$\bar{x}$ Annual discharge (m^3/s)	0.198	0.198	0.064
$\bar{x}$ Light (lux)	22,000^{a}	26,000^{a}	12,100^{b}
CPOM (g AFDM/m^2)	25.91^{a}	55.47^{a}	361.08^{b}
FPOM (g AFDM/m^2)	2.71^{a}	2.73^{a}	10.03^{b}
$\bar{x}$ Chlorophyll-a (mg/m^2)	1^{a}	43^{b}	30^{c}
Algae	low	high	moderate
Moss	low	moderate	high

* Upstream control is slightly more steep.

proximately 5 logs/50 m. Thus, although these two streams are in the same forest type, they differ in flooding history, drainage basin geomorphology, and hydrology sufficiently so that Aspen 1 is constantly reset by floods and erosion from its upper slopes to an early successional stage, whereas Aspen 2 has progressed along a successional sequence to a mid-successional stream draining the well vegetated slopes of a mid-successional forest. Likens and Bilby (1982) gave examples of streams at different stages of development depending on the level of vegetative cover and erosion and postulated a relationship between the number of debris dams and the successional state of both forest and stream.

The channel of the conifer stream was ranked as very stable. It showed no signs of modification by recent floods. The stream catchment was not burned in 1886 and there has been little erosion on the upper slopes. The stream channel contained many pools behind well-developed rock bars spaced approximately 2 m apart. Conifer logs lay across almost every rock bar, creating debris dams. Variation in width, depth, and water velocity was greater in Conifer than in the aspen streams. More stored organic matter was previously found in Conifer than in the two aspen streams (Molles 1982).

Methods

Addition and removal of wood

A 50-m upstream control and a 50-m downstream experimental reach were established on each stream, separated by a buffer zone of not less than 25 m. In early November 1983, ten aspen-log dams were added to the experimental reaches of Aspen 1 and Aspen 2, and all wood >5 cm in diameter was removed from the downstream reach of Conifer. Each dam was 0.3 m to 0.5 m high and consisted of two freshly-felled aspen logs. The logs were anchored in place by two vertical pieces of rebar on the downstream side of the dam. Black 8-mil polyethylene aprons 0.6 m wide were nailed to the upstream side of the log dams across their entire lengths to accelerate natural sealing by leaves, twigs, and needles from upstream. The apron bottom was held in place by cobble. This apron developed many small holes from abrasion by rocks, and thus was not impervious to water flow.

Estimate of stored organic matter

During spring 1984 and 1985, 10 Surber samples (0.093 m^2) from the sides and 10 from the

center of each reach were taken (n = 20/reach) to compare with standing stock estimates made previously by Molles (1982). Organisms and organic debris within the sampler frame were vigorously churned to the surface from a depth of approximately 10 cm. Fine organic particles were underestimated because the mesh size of the Surber sampler was 0.25 mm and small particles could pass through or be swept around the metal sides of the sampler. In fall 1985, 5 side and 5 center samples were collected from each reach (n = 10/reach). Organic matter was passed though a 1-mm net to separate coarse and fine particulate organic matter (CPOM > 1 mm and FPOM < 1 mm), dried for 48 hr at 100°C, ground in a Wiley mill, ashed, and weighed to obtain ash free dry mass.

Dye-measured transit time

In fall 1988, rhodamine WT and fluorescein dyes were released on the same day at the upstream end of each reach and measured periodically at the downstream end of the 50-m reach to determine transit time (Trudgill 1987). Fluorescein dye was used with rhodamine WT because it is easier to see than rhodamine WT. When dye concentrations were plotted together, their curves were identical. Concentration of rhodamine at the release point (a 50% solution in 2 L of water) was based on a preliminary experiment with fluorescein dye, a comparison of dye tracers (Smart and Laidlaw 1977), the average discharge of each stream for the day of the experiment (Aspen 1 = 16.7 L/s, Aspen 2 = 15 L/s, Conifer = 8 L/s), and the length of each reach. Sampling began downstream at the same time the two dyes were released upstream and ended when no more fluorescein dye could be seen. Each 50-m reach was then checked for remaining dye. Rhodamine concentrations were read as arbitrary units of fluorescence on a Shimatzu Spectrofluorophotometer. Rhodamine counts at the release point were 1.96 × 10^5 units of fluorescence.

Particle travel pattern and retention

In October 1983, before the addition or removal of wood from the experimental reaches and just after the peak of leaf and needle fall, 1000 small pieces of wood (2.5 cm × 2 cm × 0.5 cm) were released at the upstream ends of the two reaches on the three streams (Fig. 2). These "woodchips" were spray-painted to contrast with the yellow aspen leaves in the stream. They were uniform in size, shape, and texture to reduce differences in travel time (Young et al. 1978). The woodchips were not soaked in water before the experiment so that they were somewhat buoyant. The number of woodchips caught in a net at the downstream ends was recorded every 5 minutes after the start of the experiment for one hour and at the end of 24 hours. Woodchips remaining in the stream were collected and their position and cause of retention were recorded at the end of 24 hours. The experiment was repeated after wood was added or removed in spring and fall 1984 and in spring, late summer, and fall 1985 to determine different travel times and retention for different flow regimes. Maximum flows occur during spring runoff in May and during sudden summer thunderstorms during July and August. Low flow occurs in summer before the thunderstorm

TABLE 2. Criteria used to establish relative channel stability ranks for the three experimental streams. Scores of <38 = excellent, 39–76 = good, 77–114 = fair, and >115 = poor (Pfankuch 1975).

	Stream		
	Aspen 1	Aspen 2	Conifer
Upper banks			
Vegetative protection	6	6	3
Channel capacity	3	2	1
Lower banks			
Cutting	12	4	4
Obstructions	8	4	2
Deposition	16	8	4
Stream bottom			
Brightness	4	3	1
Consolidation	8	4	2
% Stable materials	16	8	4
Scouring and deposition	24	12	6
Moss and algae	4	3	1
Total Score	101 Unstable	44 Stable	25 Very stable

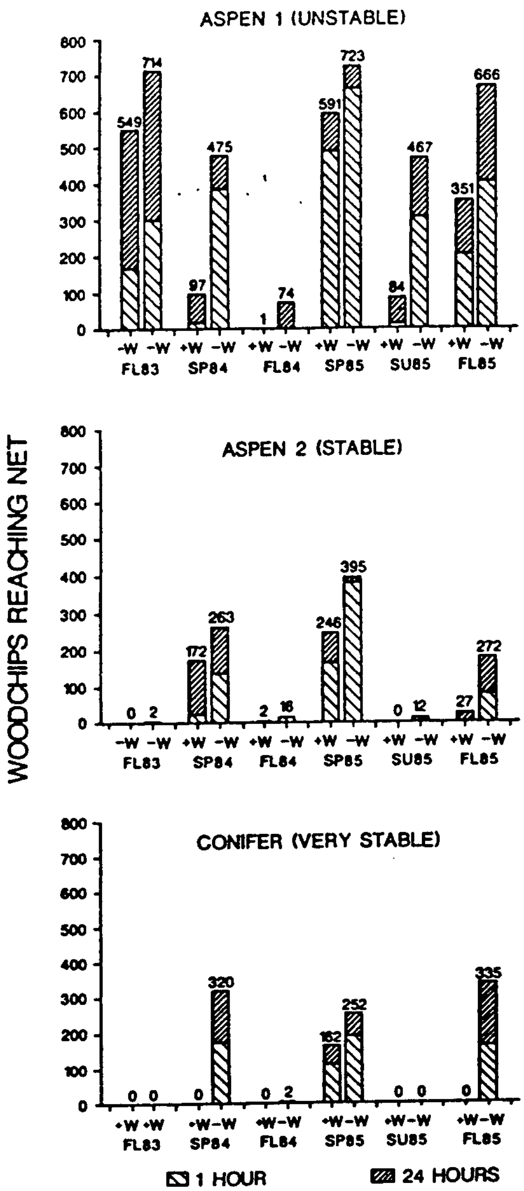

FIG. 2. Number of woodchips passing through 50-m study reaches with and without wood on three study streams during 6 seasonal experiments. SP = Spring, SU = Summer, FL = Fall, −W = Without wood, and +W = With wood. Bars are divided into number of woodchips reaching the collection net during the first hour and 24 hours after the start of the experiment. The number at the top of the bar is the total at 24 hours.

season and in late fall and winter under ice. Each batch of chips was sprayed a different color so that chips inadvertently left in the stream from previous experiments would not be included in the count of subsequent experiments.

In fall 1985, 2000 fresh aspen leaves were sprayed red and released simultaneously into each reach with 1000 woodchips to determine if neutrally buoyant leaves traveled and were retained differently from the buoyant woodchips (Fig. 3). Numbers of woodchips and leaves arriving at the downstream net were recorded for the first hour and at 24 hr. Woodchips and leaves remaining in the channel were recovered, and distance from the release point and causes of retention were recorded at 24 hr.

Statistical methods

Because each stream channel has different characteristics possibly associated with different successional status, Surber samples were subsamples (Hurlbert 1984). The statistical analysis, therefore, was based on the sum of side and the sum of center samples for each reach. In consultation with the Statistical Consulting Laboratory of the University of British Columbia, a four-way analysis of variance (factors: stream = 3, treatment = 2, collection time = 3, and position = 2) was chosen. With one datum for each cell, one can test for main effects and two-way interactions but not higher order interactions (see also Sokol and Rohlf 1981). Additionally, if there are few two-way interactions, one can assume that there are no significant higher order interactions and non-significant two-way interactions can be used to estimate the error term. In order to reduce the possibility of a Type I error and to maintain the overall significance level of the ANOVA at $p < 0.05$, a Bonferroni correction was used which set the significance level of the four-way ANOVA at $p < 0.01$ (Miller 1966).

Results

Stored organic matter

All reaches with wood contained more stored organic matter than reaches without wood ($p = 0.01$), except for the first sampling period (spring 1984) in Aspen 2 (Fig. 4). The least organic matter was stored in Aspen 1, and the most was

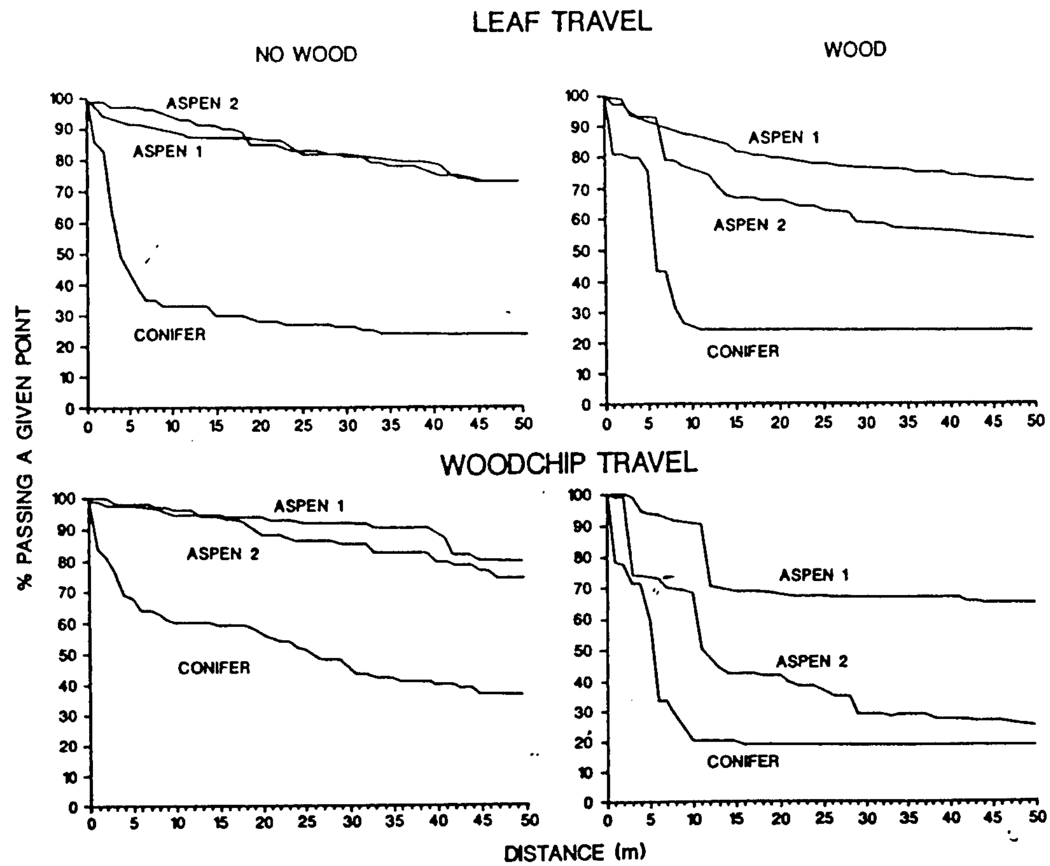

FIG. 3. Autumn 1985 retention of leaves and woodchips released simultaneously in reaches with and without wood. Position in the stream and cause of retention were recorded in the channel at 24 hr. Particles not reaching the net or found in the stream were presumed buried in the substrate. In the conifer reach with wood, leaves traveled about 13 m; woodchips traveled about 17 m.

stored in Conifer ($p < 0.001$). The average for the three collection periods for the Aspen 1 experimental reach was 226 g/m² (SD = 95) and 85 g/m² (SD = 32) for the control. The average for Aspen 2 experimental was 496 g/m² (SD = 429) and 221 g/m² (SD = 82) for the control reach. The average for the Conifer reach with wood remaining was 885 g/m² (SD = 513) and 482 g/m² (SD = 452) for the reach from which wood was removed. For all reaches, most of the organic matter (both CPOM and FPOM) was stored at the sides of the channel rather than in the center ($p = 0.001$). CPOM (coarse particulate organic matter) made up the largest part of the total collected in the streams. Organic matter in the Aspen 1 experimental reach doubled from the first to the last collection, whereas there was a seven-fold increase in the Aspen 2 experimental reach. In the Aspen 1 control reach the organic matter was half that collected from the experimental reach at the beginning of the study period. Although stored organic matter increased in this reach during the study, it was still half that of the experimental reach. There was no increase in the amount of stored organic matter collected from the Aspen 2 control reach between the beginning and the end of the study period. In the Conifer reach with natural wood remaining there was a three-fold increase in stored organic matter between spring 1984 and spring 1985, however, there was a very small increase over the entire period. In the Conifer reach without wood there was a five-fold increase between spring 1984 and spring 1985, but over the entire study period organic matter increased only by a third (185 to 258 g/m²).

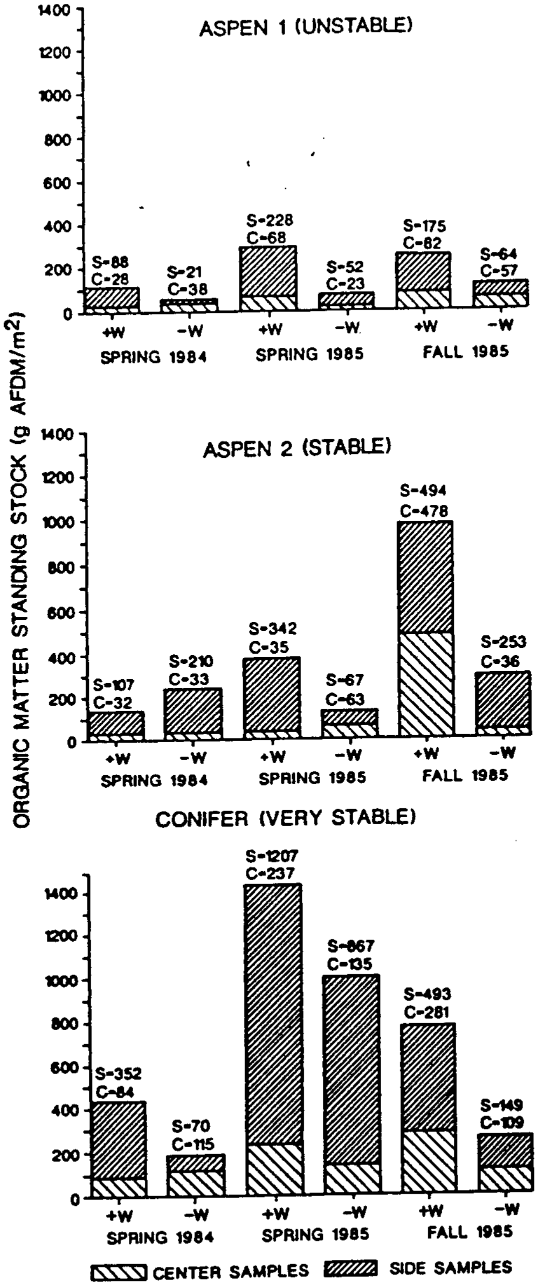

FIG. 4. Estimated standing stock of organic matter in the three study streams of different channel stabilities (unstable, stable, very stable) based on the sum of 5 Surber samples (0.093 m²) taken at the center (C) and 5 Surber samples taken at the water-land boundary (S). −W = without wood; +W = with wood.

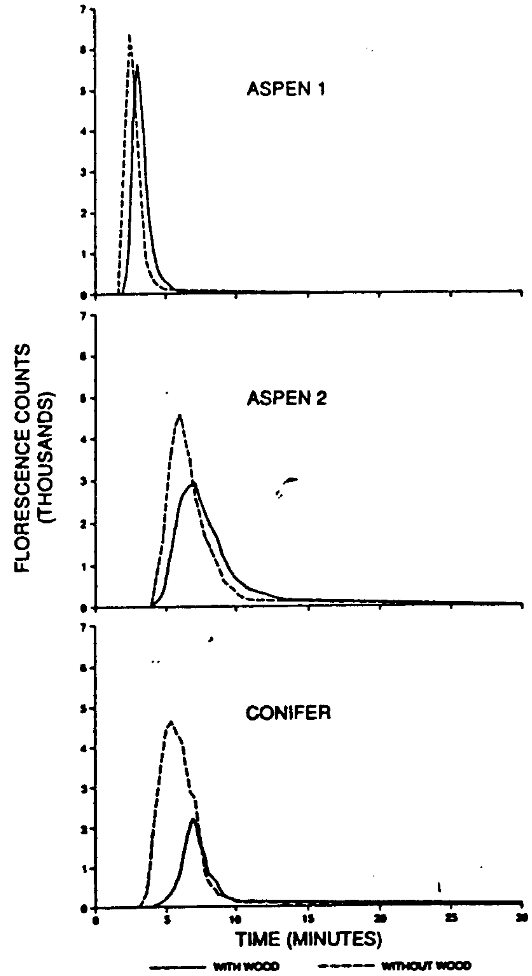

FIG. 5. Rhodamine WT dye transit through each of the six 50-m study reaches. Fluorescence counts of the concentrated dye released at the upstream end were 1.96×10^5 (50% rhodamine WT in 2 L streamwater). Reported concentrations are from samples collected at the downstream end of each reach.

There was one significant two-way interaction (stream × collection time; $p = 0.009$); the greatest amount of organic matter was collected from both reaches of Aspen 1 and Conifer during spring 1985; both Aspen 2 reaches contained most organic matter in fall 1985.

Organic matter taken from center samples during two spring sampling periods during this study (Fig. 4) and mid-channel samples of organic matter collected by Molles (Table 1) both

TABLE 3. Pretreatment mean width, depth, and water velocities ± CI (CV) (n = 26/reach) of the two reaches on Aspen 1, Aspen 2, and Conifer. Designations of wood or no wood indicate subsequent treatment of each reach. Means with different superscripts (a–e) are statistically different (Kruskal-Wallace Test with non-parametric multiple comparisons test and Bonferroni correction: $p < 0.01$; Zar 1984).

	Velocity (m/s)	Width (m)	Depth (m)
Aspen 1 (no wood)	$0.47^{a} \pm 0.08$ (42)	$1.65^{a} \pm 0.29$ (44)	$0.21^{a} \pm 0.03$ (39)
Aspen 1 (wood)	$0.48^{a} \pm 0.08$ (43)	$1.73^{a} \pm 0.23$ (32)	$0.19^{a} \pm 0.03$ (34)
Aspen 2 (no wood)	$0.52^{a} \pm 0.08$ (39)	$1.57^{a} \pm 0.22$ (34)	$0.19^{a} \pm 0.18$ (35)
Aspen 2 (wood)	$0.47^{a} \pm 0.07$ (35)	$1.79^{a} \pm 0.23$ (32)	$0.17^{a} \pm 0.03$ (35)
Conifer (no wood)	$0.26^{b} \pm 0.07$ (67)	$1.02^{b} \pm 0.21$ (50)	$0.17^{a} \pm 0.03$ (49)
Conifer (wood)	$0.24^{b} \pm 0.08$ (88)	$1.15^{b} \pm 0.16$ (35)	$0.18^{a} \pm 0.03$ (41)

show an increase from Aspen 1 to Conifer. In the present study, organic matter in center samples actually declined from spring 1984 to spring 1985, whereas organic matter in side samples increased to produce an overall increase from year to year.

Dye transit times

Dye concentrations in reaches without wood peaked at 3.00 min in Aspen 1, 5.00 min in Aspen 2, and 5.40 min in Conifer (Fig. 5). Dye concentrations in reaches with wood peaked at 3.00, 7.00, and 7.00 min, respectively. In reaches without wood dye concentrations fell to trace levels in Aspen 1 after 8.30 min, in Aspen 2 after 17.20 min, and in Conifer after 27 min. In reaches with wood dye concentrations fell to trace levels at 11.00, 25.40 min, and 27 min, respectively. Dye in the Conifer reach with wood, however, did not fall to the low levels of the Aspen streams, even after 1 hour. At the end of the experiment all reaches were checked for remaining dye. No dye could be seen in either reach of Aspen 1, dye was retained in a few backwaters and pools behind dams on Aspen 2, and much of the dye in the Conifer reach with wood was circulating in backwaters and in pools behind dams upstream of the collection point.

Water velocity and stream morphology

The six study reaches did not differ significantly before treatment in depth, and the four aspen reaches had comparable velocity and width. The two conifer reaches had comparable depths, water velocities, and widths, but both were more narrow and lower in velocity than the aspen reaches (Table 3).

Generally, there was a decrease in average point velocity and an increase in stream average width and depth after logs were added to both the early and mid-successional aspen streams (Table 4). Velocity increased and stream width and depth decreased when wood was removed from the climax conifer stream. In all but the experimental reach of Aspen 2, variation in width, depth, and water velocity was greater in reaches with wood than in reaches without wood. Water depth in Aspen 2 experimental was less variable (34%) than depth in the control reach (55%). Addition of logs created the most variability in depth in Aspen 1 experimental reach but the least variability in width and velocity. Variability was low during high water and high during low water (Table 4).

Particle retention

Before wood addition or removal, the number of woodchips traveling through control and experimental reaches on each stream was similar (Fig. 2). The upstream control reach of Aspen 1, however, had a slightly steeper slope than the experimental reach (11° vs. 10°). Retention was lowest in Aspen 1 and highest in Conifer. The addition of wood to Aspen 1 did not seem to change the relative retention of the two reaches very much. The addition of wood increased retention in the experimental reach of Aspen 2 by about 25% during high spring flow or moderate autumn flow (autumn 1985). The removal of wood from Conifer reduced retention of woodchips by about 30% during high and moderate flow periods (after recharge from

TABLE 4. Mean velocities (m/s), widths (m), and depths (m) ± CI (CV) in Aspen 1, Aspen 2, and Conifer after the addition or removal of wood. Numbers within years with different superscripts are statistically different ($p < 0.01$; Kruskal-Wallace Test with non-parametric multiple comparisons test, Zar 1984).

	1984 Spring	1985 Spring (early)	1985 Spring (late)	1985 Summer
		Velocity		
Aspen 1				
No wood	$1.55^{a} \pm 0.27$ (24)	$1.89^{a} \pm 0.41$ (19)	$1.44^{a} \pm 0.36$ (37)	$0.62^{a} \pm 0.23$ (59)
Wood	$1.08^{b} \pm 0.29$ (24)	$1.49^{b} \pm 0.28$ (27)	$1.12^{a} \pm 0.31$ (42)	0.59 ± 0.17 (46)
Aspen 2				
No wood	$1.48^{a} \pm 0.64$ (32)	$1.52^{b} \pm 0.24$ (22)	$1.24^{a} \pm 0.12$ (15)	$0.57^{b} \pm 0.13$ (35)
Wood	$1.25^{c} \pm 0.31$ (34)	$1.30^{c} \pm 0.31$ (26)	$1.21^{b} \pm 0.21$ (26)	$0.45^{b} \pm 0.18$ (65)
Conifer				
No wood	$0.68^{d} \pm 0.20$ (41)	$1.36^{c} \pm 0.34$ (35)	$1.20^{b} \pm 0.29$ (36)	$0.40^{b} \pm 0.14$ (57)
Wood	$0.34^{e} \pm 0.17$ (70)	$1.34^{c} \pm 0.31$ (32)	$0.67^{c} \pm 0.20$ (45)	$0.26^{c} \pm 0.13$ (81)
		Width		
Aspen 1				
No wood	$1.55^{a} \pm 0.27$ (24)	$1.89^{a} \pm 0.41$ (32)	$1.44^{a} \pm 0.36$ (40)	$1.56^{a} \pm 0.46$ (38)
Wood	$2.82^{b} \pm 0.76$ (38)	$2.91^{b} \pm 0.62$ (30)	$2.03^{b} \pm 0.60$ (47)	$2.01^{b} \pm 0.56$ (39)
Aspen 2				
No wood	$2.43^{b} \pm 0.55$ (33)	$2.02^{a} \pm 0.32$ (22)	$1.31^{a} \pm 0.25$ (30)	$1.80^{a} \pm 0.41$ (32)
Wood	$2.94^{b} \pm 1.27$ (58)	$3.70^{c} \pm 0.91$ (35)	$2.07^{c} \pm 0.39$ (30)	$2.72^{c} \pm 0.64$ (33)
Conifer				
No wood	$1.13^{c} \pm 0.27$ (34)	$1.90^{a} \pm 0.43$ (32)	$1.13^{d} \pm 0.27$ (36)	$0.87^{d} \pm 0.17$ (27)
Wood	$1.65^{a} \pm 0.44$ (38)	$1.56^{a} \pm 0.47$ (45)	$1.16^{d} \pm 0.29$ (45)	$1.28^{a} \pm 0.29$ (31)
		Depth		
Aspen 1				
No wood	$0.28^{a} \pm 0.06$ (28)	$0.30^{a} \pm 0.06$ (26)	$0.12^{a} \pm 0.03$ (41)	$0.11^{a} \pm 0.01$ (15)
Wood	$0.32^{a} \pm 0.04$ (19)	$0.27^{a} \pm 0.03$ (16)	$0.19^{a} \pm 0.17$ (145)	$0.12^{a} \pm 0.02$ (26)
Aspen 2				
No wood	$0.36^{a} \pm 0.31$ (123)	$0.30^{a} \pm 0.05$ (43)	$0.15^{a} \pm 0.04$ (43)	$0.20^{a} \pm 0.04$ (31)
Wood	$0.34^{a} \pm 0.31$ (31)	$0.32^{a} \pm 0.04$ (17)	$0.21^{a} \pm 0.07$ (52)	$0.25^{a} \pm 0.07$ (38)
Conifer				
No wood	$0.13^{b} \pm 0.02$ (19)	$0.25^{a} \pm 0.04$ (23)	$0.11^{b} \pm 0.02$ (30)	$0.13^{b} \pm 0.04$ (42)
Wood	$0.28^{a} \pm 0.10$ (48)	$0.29^{a} \pm 0.05$ (23)	$0.16^{a} \pm 0.05$ (52)	$0.23^{a} \pm 0.06$ (38)

summer thunderstorms and during spring runoff). During low flow (fall 1984 and summer 1985), no woodchips moved through either control or experimental Conifer reaches.

Based on the average for all experiments, the reach with dams added retained 72% of the woodchips released, and the reach without wood retained 49% of the woodchips released in Aspen 1. The passage of woodchips in the Aspen 2 reach with dams was reduced to 25% of those passing through the control, and the number of woodchips passing through the Conifer reach with natural wood was 11% of those moving through the cleared reach.

Leaves were released only in autumn 1985 (Table 5). In Aspen 1 the control reach retained 43% of 2000 leaves released and the reach with dams retained 82%. The Aspen 2 reach without dams retained 85% of leaves released and the reach with dams retained 98%. The Conifer reach with wood retained 100% of leaves released and the reach without wood retained 99%. There was a 91% difference between the two Aspen 1 reaches, a 15% difference between the two As-

TABLE 5. Number of leaves retained of 2000 released simultaneously with 1000 woodchips, autumn 1985.

Stream	Treatment	No. Leaves Retained
Aspen 1	No wood	855
	Wood	1636
Aspen 2	No wood	1705
	Wood	1963
Conifer	No wood	1984
	Wood	2000

pen 2 reaches, and a 1% difference between the Conifer reaches (Table 6).

Particle travel pattern

Travel patterns of woodchips and leaves through the six reaches conformed fairly well to a negative exponential model: $Y_d = Y_0 e^{-kd}$, where Y_d is the percentage of particles passing point d; Y_0 is the percentage of particles in transport at point 0; k is the retention rate; and d is distance (Fig. 3). Particle retention rates (k) were least in reaches without dams or natural wood, and highest in streams with dams or wood, with the exception of the retention rate of leaves in Conifer, which was the same for both experimental and control reaches (Fig. 6). Retention rates were lowest in Aspen 1 and highest in Conifer. Reaches with wood had a higher retention rate of woodchips than of leaves. Aspen reaches without wood had similar woodchip and leaf retention rates but a higher leaf than woodchip retention rate for the conifer reach without wood. Since there were no replicate streams, a statistical comparison of the slopes of log transformed data used by Webster et al. (1987) for replicate experiments in laboratory streams cannot be made. Retention efficiency, as well as uptake length of particles (Webster et al. 1987), and percent change in both, however, are shown in Table 6. Retention efficiency (RE) is the percent of particles retained within the stream and uptake length (UL) is the inverse of the retention rate calculated over the 50-m reach. In autumn 1985, greatest difference in woodchip retention efficiency was between the control and experimental reaches of Aspen 1,

TABLE 6. Retention efficiencies (RE) and uptake lengths (UL) of stream reaches for woodchips and leaves released simultaneously, autumn 1985. UL is the distance required to retain 63.2% of the total number of particles.

Stream	Treatment	RE (%)	Change (%)	UL (m)	Change (%)
		Woodchips			
Aspen 1	No wood	33		125	
	Wood	65	+97	48	−62
Aspen 2	No wood	73		39	
	Wood	97	+33	14	−62
Conifer	No wood	67		46	
	Wood	100	+49	11	−76
		Leaves			
Aspen 1	No wood	43		90	
	Wood	82	+91	29	−67
Aspen 2	No wood	85		26	
	Wood	98	+15	13	−50
Conifer	No wood	99		11	
	Wood	100	+1	10	−0.5

which doubled. The retention efficiency of Conifer reaches differed by 50%, whereas Aspen 2 retention efficiency of the experimental reach was 33% higher than the control. Overall, reaches had higher retention efficiencies for leaves than for woodchips (e.g., 33% versus 45% in Aspen 1). The difference in leaf retention efficiencies were greatest in Aspen 1 (+91%) but small in Aspen 2 (+15%) and negligible in Conifer (+1%).

Particle retention mechanisms

Dams stopped particles, deflected flow, and changed water velocity, which altered width and depth of the stream. Dams stopped most woodchips and leaves in Aspen 2 and Conifer. Leafpacks, rocks, wood, and other obstacles were also important barriers, especially during the autumn 1985 experiment (Table 7). Large leafpacks (up to 0.6 m long) that built up on the streambed were prominent barriers. Woodchips were also caught in eddies, backwaters, and undercuts, while leaves were often stopped by cobbles in the channel. In this experiment, experimental dams were not important obstacles in Aspen 1. Most woodchips and leaves were

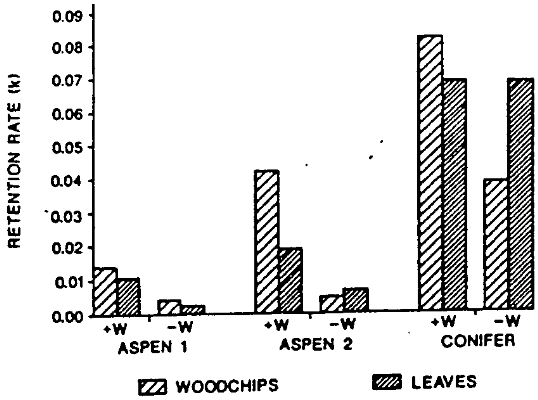

FIG. 6. Average retention rates of woodchips and leaves released simultaneously in study reaches with and without wood, autumn 1985.

caught behind experimental dams in Aspen 2 and secondarily by rocks. Rocks were primary obstacles in the Aspen 2 control reach, although leaves also stuck to several large conifer logs that lay parallel to and formed part of the streambank. Wood caught most particles in the Conifer reach with debris dams, but rocks were the primary obstacles in the Conifer reach without debris dams.

Discussion

This study demonstrates that adding wood to streams increases retention and storage and shows some mechanisms by which particles are retained directly or deflected from the thalweg into still-water areas where they are stored. Hedin et al. (1988) proposed a direct relationship between the number of logs in a stream and the successional state of the forest through which the stream runs and suggests that disturbances in forests can impact streams for 100 years or more. According to Hedin et al. (1988), twenty years after a fire should be the time of lowest number of logs in a stream. In the present study, Aspen 1 had no logs in the channel before treatment, Aspen 2 had approximately 5 dams/50 m, and Conifer had approximately 20–25 dams/50 m. If the Hedin et al. (1988) model is applied to Tesuque streams, Aspen 1 was advanced in time from 20 years after a fire to 55 years with addition of 10 dams, and Aspen 2 was advanced from 55 to 80 years when the addition of 10 dams brought its total to 15/50 m. Removing all wood from the Conifer reach reset it from about 250 years to approximately 20 years after a major disturbance.

Organic matter storage

In the present study, there was a greater increase of stored organic matter behind added dams in the mid-successional than in the early-successional stream. These findings corroborate other research showing a positive correlation between the amount of stored organic matter and the presence of debris dams (Bilby and Likens 1980, Bilby 1981, Likens and Bilby 1982, Molles 1982, and Hedin et al. 1988). Although this study and Molles (1982) used the Surber sampler to estimate organic matter in streams, Molles sampled at one time during the year, after iceout in late April before spring runoff. His estimates may be lower than mine because my samples were taken when organic matter in the substrate was low (after winter processing and before major additions in the fall). Therefore one could expect to find the least stored organic matter in both streams. In the present study the amount of organic matter in the center samples decreased with time, while the side samples increased. Pools behind debris dams incorporated former bank areas that were rich in organic matter which accounts for higher organic matter values for side samples. Results are also consistent with Swanson et al. (1982), who reported that 90% of sediment in forested headwater streams was stored behind woody debris. Bilby and Likens (1980) and Bilby (1981) showed that removing woody debris increased export of particulate organic matter, but they did not add wood experimentally. The present study demonstrates that wood addition increases stored organic matter within a short time. This result underscores the rapidity with which some streams can respond to physical changes within stream channels (e.g., Fisher et al. 1982, Molles 1985).

Water routing and channel morphology

Wood in streams changes the routing of water, water velocity, and channel width and depth. Dye tracers have been used in a few studies to determine transit times of water and subsequent transport of dissolved organic carbon and nutrients in different stream types (Smart and

TABLE 7. Retention mechanisms of woodchips and leaves released simultaneously in Aspen 1, Aspen 2, and Conifer, autumn 1985. Number in parentheses = % of total particles retained. "Rocks" includes both bar rocks and leaf-coated rocks.

	Particle Type	Cause of Retention	
		Primary	Secondary
Aspen 1			
No wood	Woodchips	Leaves (49)	Eddies + backwaters (18)
	Leaves	Leaves (33)	Rocks (21)
Wood	Woodchips	Undercut (63)	Dams (12)
	Leaves	Leaves (41)	Rocks (20), dams (18)
Aspen 2			
No wood	Woodchips	Rocks (58)	Various (42)
	Leaves	Rocks (42)	Wood in bank (22)
Wood	Woodchips	Dams (44)	Rocks (42)
	Leaves	Dams (62)	Rocks (18)
Conifer			
No wood	Woodchips	Rocks (80)	Wood in bank (7)
	Leaves	Rocks (75)	Bank (18)
Wood	Woodchips	Wood (88)	Undercut (8)
	Leaves	Wood (99)	Undercut (1)

Laidlaw 1977, Bencala et al. 1984, Munn and Myer 1988). Here, rhodamine WT was used to determine water transit times in streams of different successional states, with and without wood. Bilby and Likens (1980) found that removing log dams also removed small waterfalls over which stream energy was dissipated. Lack of energy dissipation favors transport rather than storage. Dissipation of energy in reaches with wood was shown in Tesuque streams by decreased velocity (Table 4), increased transit time of water, higher retention efficiencies, reduced uptake lengths (Table 6), and deflection of dye-carrying water into eddies and pools behind dams (Fig. 5). The transit time of water in streams was also increased by increased morphological heterogeneity, which created more complex current flow, dissipation of energy, increased water transit time, increased storage areas, and new sources of organic material from from flooded banks behind new dams (Keller and Swanson 1979, Keller and Tally 1979). Decreased morphological heterogeneity reduced the complexity of water flow and decreased energy dissipation, residence time of water, number of storage areas, and source areas of organic matter as the active channel narrowed in Conifer reaches from which wood was removed. Log removal resulted in the inverse patterns produced by log addition giving strong evidence of a predictable relationship between the amount of wood and organic matter storage observed in Tesuque streams (Molles 1982) and in other streams before and after logging (Bilby and Likens 1980, Bilby 1981, Sedell et al. 1988).

Organic particle retention rates and travel patterns

Wood increased retention rates of POM (particulate organic matter) directly by catching particles and indirectly by altering particle travel patterns. Some particles followed the thalweg (line of least resistance down the channel), but many were deflected (like the dye-carrying water) into eddies and backwaters along the channel (Table 7). As found by Young et al. (1978), different sizes and shapes of particles traveled at different rates. In this study moist leaves were neutrally buoyant in the water column and were caught by obstructions within the water column. Dry woodchips rode on the water surface and were frequently deflected from the thalweg by the dams. Retention rates of leaves and woodchips were similar in aspen reaches without dams (Fig. 3). The retention rate for leaves was higher than for woodchips in the Conifer reach from which wood was re-

moved. During autumn low flows, however, the larger and less buoyant leaves ran aground on the edges of the stream and stream bottom, whereas the woodchips floated on the surface. Therefore it appears that greater physical heterogeneity in channel morphology in mid-and-late-succession resulted in retention of a greater diversity and quantity of organic particles, providing a larger variety of habit and food for benthic invertebrates.

During the autumn low flow period, where there is reduced channel roughness (Sedell et al. 1988), the travel pattern curve will conform closely to a negative exponential model with a shallow slope, indicating that the number of particles exceeds storage capacity. In such conditions, particulate organic matter will have a low probability of being incorporated into the stream system as a structural or nutritional component near the entry point. If the curve is discontinuous and the slope steep (indicating discrete zones of high retention), storage capacity exceeds particle number and processing will occur close to the entry point. Results of the woodchip experiments, in particular, reveal the functional significance of retention structures within streams. Reaches without wood were structurally and functionally more homogeneous than reaches with wood. The presence of woody debris tended to divide the reach into discrete subunits with differing retention efficiencies. The stepped travel pattern in reaches with wood (e.g., Fig. 3) represented both actual "steps" of wood within the channel, as well as divisions between different habitat in the stream on a smaller scale than that of the entire reach. These results support the view of streams as discontinuous geomorphic units of varying scales (Gregory et al., in press).

Interactions between wood and basin geomorphology

The amount and type of wood added during forest succession is not the only factor producing structural and functional differences between the study streams. For example, even through the two aspen streams are in the same forest type, they differed considerably in channel stability because of differences in upslope processes, which are also associated with succession in the terrestrial ecosystem. Two consequences of the more extensive erosion and lack of vegetation cover in the upper drainage basin of Aspen 1 were: 1) large, angular gravel was constantly added to the stream channel, and 2) large floods occurred more often in this stream than in Aspen 2 (Molles 1985). As a consequence, the channel of Aspen 1 was unstable and its gravel substrate lacked visible primary producers. Immediately following the installation of the dams in the fall, large, deep pools formed behind the logs in both aspen streams. By the next spring, however, pools behind dams in Aspen 1 were filled with gravel uncolonized by algae, whereas deep pools still existed behind the added dams in Aspen 2 and the cobble substrate was colonized by algae. Heede (1972) showed that there were two kinds of energy dissipators in streams: 1) inflexible logs and 2) flexible substrate such as gravel. Gravel cannot be stabilized within a channel until logs are present to make a barrier behind which gravel steps can form. This is certainly what happened in Aspen 1. The absolute number of particles retained was not as high as in the other two more stable streams, but the difference between the reaches with and without logs was greatest because the logs acted as stabilizers and dissipators of energy on this unstable reach, which had previously contained nothing to impede the passage of gravel down the channel with spring runoff. The combination of high erosion and lack of dams was resetting this stream frequently to an early successional stage. The added dams prevented complete resetting of this experimental reach. Dams in Aspen 1, however, trapped far fewer woodchips and leaves (12% and 18%, respectively) compared to dams in Aspen 2 (44% and 62%). The few woodchips and leaves retained by Aspen 1 simply ran aground on the shifting gravel. Even though the streams had similar discharge in autumn 1988 (Aspen 1 = 16.7 L/s; Aspen 2 = 15.0 L/s), dye transit time in the more stable Aspen 2 channel was twice that of the Aspen 1 channel (Fig. 5).

Aspen 1 was structurally more homogeneous, and was similar to sandy-bottom streams studied by Leff and McArthur (1988). Debris dams in sandy-bottomed streams were also ineffective in reducing seston movement during storms. Aspen 2 was structurally more heterogeneous, like the streams studied by Golladay et al. (1987) and Webster et al. (1988) where wood reduced seston movement during storms.

Although forest type and the amount of wood in streams are predictors of relative particle retention, the amount of organic matter standing

stock, and the composition of the stream invertebrate community (Molles 1982, Speaker et al. 1984, Trotter 1987), it must be realized that changes in the organic component of stream structure and function are related to drainage basin geomorphology, parent geology, erosion, climate, and weather patterns, which have a large impact on channel stability. Both the geomorphic characteristics of the drainage basin (some of which change over forest succession) and the successional status of plant communities in each basin should be considered together for each site studied to predict morphological, functional, and community level changes in streams as succession proceeds. This interplay between change in plant community, change in streams, and change in drainage basin geomorphology over time is an example of the strong connection between the stream and its valley (Hynes 1975).

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Literature Cited

BENCALA, K. E., R. E. RATHBUN, A. P. JACKMAN, V. C. KENNEDY, G. W. ZELLEWEGER, AND R. J. AVANZINO. 1984. Rhodamine WT dye losses in a mountain stream environment. Water Resources Bulletin 19:943–950.

BENKE, A. C., R. L. HENRY III, D. M. GILLESPIE, AND R. H. HUNTER. 1985. Importance of snag habitat for animal production in Southeastern streams. Fisheries 10:8–13.

BILBY, R. E. 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. Ecology 62: 1134–1143.

BILBY, R. E., AND G. E. LIKENS. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology 60:1107–1113.

FISHER, S. G., L. J. GRAY, N. B. GRIMM, AND D. E. BUSCH. 1982. Temporal succession in a desert stream ecosystem following flash flooding. Ecological Monograph 52:93–110.

GOLLADAY, S. W., J. R. WEBSTER, AND E. F. BENFIELD. 1987. Changes in stream morphology and storm transport of seston following watershed disturbance. Journal of the North American Benthological Society 6:1–11.

GOSZ, J. R. 1975. Nutrient budgets for undisturbed ecosystems along an elevational gradient in New Mexico. Pages 780–799 *in* F. G. Howell, J. G. Gentry, and M. H. Smith (editors). Mineral cycling in Southeastern ecosystems. Energy Research and Development Agency Symposium Series CONF-74513, Springfield, Virginia.

GREGORY, S. V., F. J. SWANSON, AND W. A. MCKEE. In Press. An ecosystem perspective of riparian zones. BioScience.

HARMON, M. E., J. F. FRANKLIN, F. H. SWANSON, P. SOLLINS, S. V. GREGORY, J. D. LATTIN, N. H. ANDERSON, S. P. CLINE, N. G. AUMEN, J. R. SEDELL, G. W. LIENKAEMPER, K. CROMACK, JR., AND K. W. CUMMINS. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133–302.

HEDIN, L. O., M. S. MAYER, AND G. E. LIKENS. 1988. The effect of deforestation on organic debris dams. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 23:1135–1141.

HEEDE, B. H. 1972. Influence of a forest on the hydraulic geometry of two mountain streams. Water Resources Bulletin 8:523–530.

HURLBERT, S. H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187–211.

HYNES, H. B. N. 1975. The stream and its valley. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 19:1–5.

KELLER, E. A., AND F. H. SWANSON. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4:361–380.

KELLER, E. A., AND T. TALLY. 1979. Effects of large organic debris on channel form and fluvial processes in the coastal redwood environment. Pages 66–70 *in* D. D. Rhodes and G. P. Williams (editors). Adjustments on the fluvial system. State University of New York, Binghamton, New York.

LEFF, L. G., AND J. V. MCARTHUR. 1988. Seston and dissolved organic carbon transport during storm flows in a natural and a disturbed coastal plain stream. Journal of Freshwater Ecology 4:271–277.

LIKENS, G. E., AND R. E. BILBY. 1982. Development, maintenance, and the role of organic-debris dams in New England streams. Pages 122–128 *in* Swanson, F. J., R. J. Janda, T. Dunne, and D. N. Swanson (editors). Forest Service Research Paper PNW-141. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

MILLER, R. G. 1966. Simultaneous statistical inference. McGraw-Hill Book Company, New York.

MOLLES, M. C., JR. 1982. Trichopteran communities of streams associated with aspen and conifer forests: long-term structural change. Ecology 63:1–6.

MOLLES, M. C., JR. 1985. Recovery of a stream invertebrate community from a flash flood in Tesuque Creek, New Mexico. The Southwestern Naturalist 30:279–287.

MOLLES, M. C., AND C. N. DAHM. 1990. El Niño, La Niña, and North American stream ecology. Journal of the North American Benthological Society. 9:68–76.

MUNN, N. L., AND J. L. MYER. 1988. Rapid flow through the sediments of a headwater stream in the southern Appalachians. Freshwater Biology 20:235–240.

NILSON, H. C., AND R. W. LARIMORE. 1973. Establishment of invertebrate communities on log substrates in the Kaskaskia River, Illinois. Ecology 54:366–374.

PARSONS, T. R., Y. MAITA, AND C. M. LALLI. 1984. A manual of chemical and biological methods for seawater analysis. Pergamon Press, New York, New York.

PFANKUCH, D. J. 1975. Stream reach inventory and channel stability evaluation. United States Forest Service, Region 1, Missoula, Montana.

SEDELL, J. R., P. A. BISSON, F. J. SWANSON, AND S. V. GREGORY. 1988. What we know about large trees that fall into streams and rivers. Pages 47–79 *in* C. Maser, R. F. Torrant, J. M. Trappe, and J. F. Franklin (editors). From the forest to the sea: a story of fallen trees. USDA Forest Service General Technical Report PNW-GTR-229. Pacific Northwest Research Station, Portland, Oregon.

SMART, P. L., AND I. M. S. LAIDLAW. 1977. An evaluation of some fluorescent dyes for water tracing. Water Resources Research 13:15–33.

SOKOL, R. R., AND F. J. ROHLF. 1981. Biometry. W. H. Freeman and Company, San Francisco, California.

SPEAKER, R. 1985. Distribution and retention of particulate organic matter in streams in the Cascade Mountains of Oregon. Masters thesis, Oregon State University, Corvallis, Oregon.

SPEAKER, R., K. MOORE, AND S. GREGORY. 1984. Analysis of the process of retention of organic matter in stream ecosystems. Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie 22:1835–1841.

SWANSON, F. H., S. V. GREGORY, J. R. SEDELL, AND A. G. CAMPBELL. 1982. Land-water interactions: the riparian zone. Pages 267–291 *in* R. L. Edmonds (editor). Analysis of coniferous forest ecosystems in the western United States. Hutchinson Ross Publishing Company, Stroudsberg, Pennsylvania.

TRISKA, F. J., J. R. SEDELL, AND S. V. GREGORY. 1982. Coniferous forest streams. Pages 292–232 *in* R. L. Edmonds (editor). Analysis of coniferous forest ecosystems in the western United States. Hutchinson Ross Publishing Company, Stroudsberg, Pennsylvania.

TROTTER, E. H. 1987. An experimental test of the hypothesis that the addition of wood from forests to streams drives stream succession. Ph.D. Dissertation, University of New Mexico, Albuquerque, New Mexico.

TRUDGILL, S. T. 1987. Soil water dye tracing, with special reference to the use of Rhodamine WT, Lissamine FF and Amino G Acid. Hydrological Processes 1:149–170.

USGS. 1973. Water resources data for New Mexico Part 1: surface water record. United States Geological Survey, Albuquerque, New Mexico.

VANNOTE, R. L., G. W. MINSHALL, K. W. CUMMINS, J. R. SEDELL, AND C. E. CUSHING. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:370–377.

WEBSTER, J. R., E. F. BENFIELD, S. W. GOLLADAY, B. H. HILL, L. E. HORWICK, R. F. KAZMIERCZAK, JR., AND W. B. PERRY. 1987. Experimental studies of physical factors affecting seston transport in streams. Limnology and Oceanography 32:848–863.

WEBSTER, J. R., E. F. BENFIELD, S. W. GOLLADAY, R. F. KAZMIERCZAK, JR., W. B. PERRY, AND G. T. PETERS. 1988. Effects of watershed disturbance on stream seston characteristics. Pages 279–296 *in* W. T. Swank and D. A. Crossley, Jr. (editors). Forest hydrology and ecology at Coweeta. Springer-Verlag, New York.

YOUNG, S. A., W. P. KOVALAK, AND K. A. DEL SIGNORE. 1978. Distances travelled by autumn-shed leaves introduced into a woodland stream. American Midland Naturalist 100:217–222.

ZAR, J. H. 1984. Biostatistical analysis. Second Edition. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

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Role of wood debris in modifying channel geomorphology and riparian areas of a large lowland river under pristine conditions: A historical case study

Frank J. Triska

With 7 figures and 4 tables in the text

Introduction

"... the raft is not standing still, but is gradually progressing upwards, like a destroying angel, spreading desolation over a most lovely country ..." (Paxton 1828).

A major impact of civilization on forested environments has been a severe reduction in the amount of dead wood debris both on the forest floor and in associated fluvial environments (Triska & Cromack 1981). Even in well managed forests of Europe the amount of wood debris on the forest floor is often small (0—5 metric tons per hectare; Swift et al. 1976; Christensen 1977). By comparison, in unimpacted forests of the Pacific Northwest, U. S. A., amounts of wood debris can exceed 200 metric tons per hectare (Grier & Logan 1977; Mac Millan et al. 1977).

When they are present, fallen logs constitute important habitats in forested and fluvial environments. Wood-generated habitat in streams can serve as fish refugia during freshets, and rearing sites for young of the year (Bustard & Narver 1975; Sedell et al. 1981). Wood provides sites for oviposition, pupation and emergence by fish food invertebrates (Anderson et al. 1981). Wood debris can be a site for N-fixation (Buckley & Triska 1978). Clumped debris can serve as retention sites for leaf litter and other particulate organic matter (Sedell & Triska 1977; Naiman & Sedell 1979; Bilby & Likens 1980; Bilby, R. E. 1981; Triska et al. 1982). Geomorphologically, wood debris can result in a stairstep series of dams and falls which collect mineral sediment, control sediment routing, and may significantly control the stream's gradient (Heede 1972; Swanson et al. 1976; Keller & Swanson 1979; Keller & Talley 1979).

Beneficial roles for wood-generated habitat have only recently been reported and then almost exclusively in small streams. In major rivers the ecological role of wood will never be well understood, because it has been systematically removed for more than a century as a hazard to commercial navigation (Sedell & Luchessa 1982). Absence of wood habitat in the current geomorphology and ecology of large rivers should not imply its role was previously negligible. In fact, wood debris was occasionally a major pool of organic carbon and a factor in overall geomorphology of rivers in many sections of the United States (Sedell & Luchessa 1982; Minckley & Runne in press). As navigable river basins of the United States have undergone extensive anthropogenic manipulation, any account of wood debris in large pristine rivers of the United States is necessarily historical. In this report we will demonstrate the role of wood debris in: (1) modifying riparian areas by creation of lakes, (2) altering the function of tributary channels and (3) modifying the main channel of the Red River in Louisiana, U. S. A. The period of record is 1827 to 1920.

Site description

Most data presented here chronicle events which occurred between Shreveport, La. and the Arkansas border (Fig. 1), although the total raft region extended south of Natchitoches. Data on removal of navigational hazards after 1982 encompass a reach from Alexandria, La. to Fulton, Ak.

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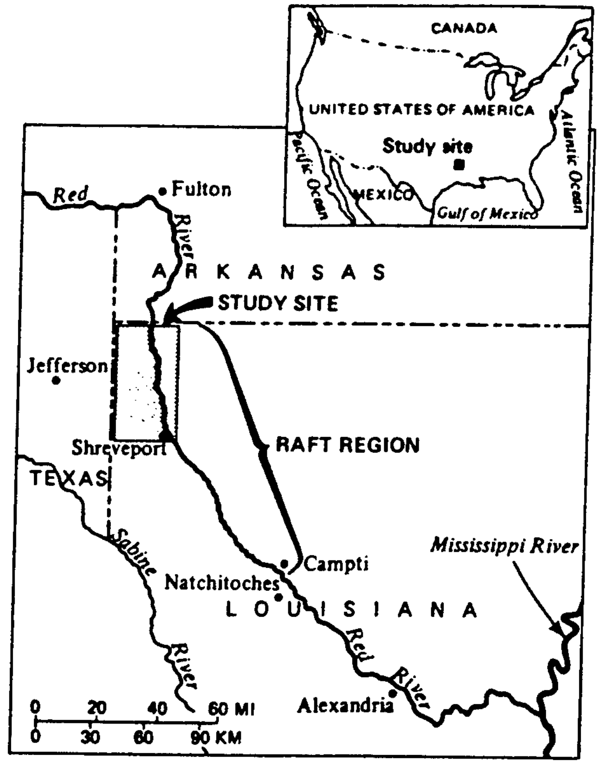

Fig. 1. Map of study site.

800km of river affected by wood

(approx. 800 river km). Data in the following site description are from HOLLE (1950), Red River Basin Coordinating Committee (1968), and MARTIEN (1978).

The Red River, approximately 1200 km long, is the southernmost major tributary of the Mississippi (Fig. 1) with a total drainage basin of approximately 236,000 km^2. In northern Louisiana the river meanders extensively through lowland alluvial deposits. Natural levees, oxbow lakes and abandoned stream channels are predominant physiographic features. The present stream width ranges from 215 to 365 m between unstable banks. Suspension of large quantities of red ferruginous sediment from Pennsylvanian and Permian rocks in the western part of the basin, and Tertiary iron bearing minerals in Louisiana, provide the river's name. Suspended sediment load currently averages 93,500 metric tons per day (Alexandria, La.). River water is high in chloride, sulfate and dissolved solids. Prior to flood control the drainage was subject to severe intermittent flooding caused by rapid storm runoff from semiarid areas. Highest recorded discharge is 8570 $m^3 \cdot s^{-1}$ and lowest about 20 $m^3 \cdot s^{-1}$ at Shreveport, La. Average instantaneous discharge is 705 $m^3 \cdot s^{-1}$, and average annual discharge is $2.22 \times 10^{10} m^3$ at the same location (period of record 1928—1975). The climate is mild with moderate winters and long summers. Average annual temperature is 18 °C. Precipitation is typically 100—130 cm · $year^{-1}$ in the vicinity of Shreveport.

Results and discussion

Federal interest in the Red River Valley began in 1806, three years after the Louisiana Purchase when a 24-man "Exploring Expedition of the Red River" was initiated by the U. S. War Department. The party expected to ascend the Red River in boats and proceed upriver to its source; however, they "encountered many difficulties in the navigation of the river in the vicinity of a great raft, but finally overcame them all and found themselves upon the river above this formidable obstacle" (MARCY 1854).

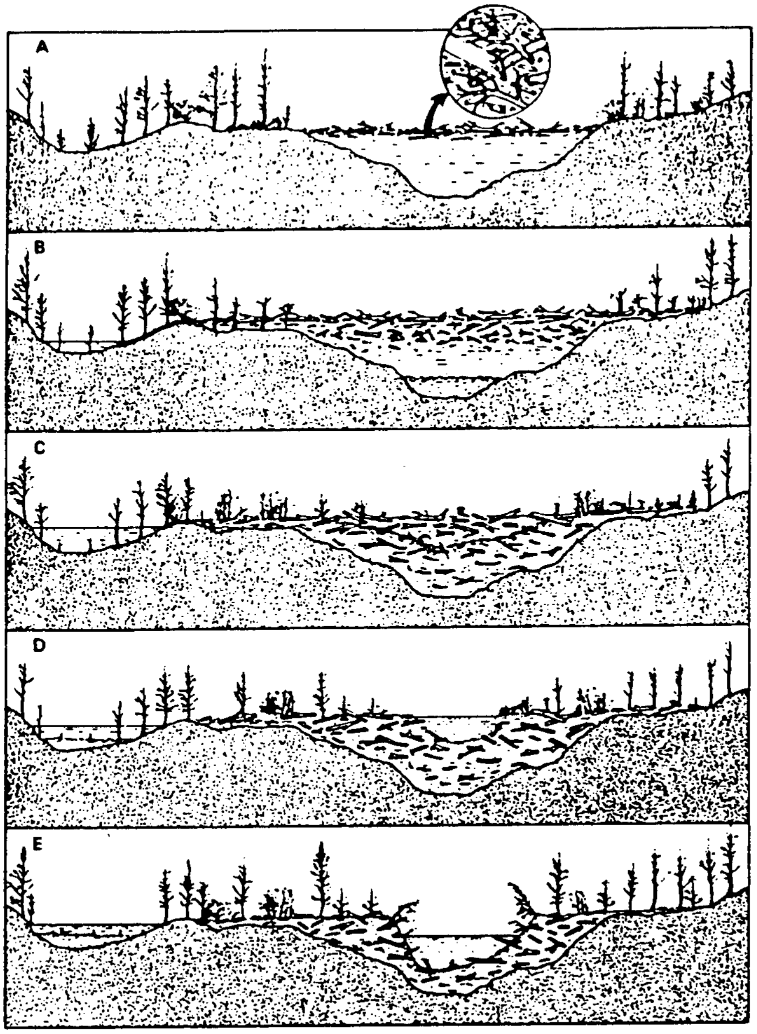

Fig. 2. Schematic diagram of chronological processes (80—150 years) associated with the natural formation and destruction of debris dams on Red River. A: Initial debris clogging and filling of interstitial spaces. B: Submersion of floating debris by waterlogging and additional debris accumulation. Initial channel aggradation, bank deposition and flooding of riparian areas. C: Enlargement and deepening of riparian lakes, death of inundated timber, growth of riparian species and alluvium deposition along channel margins. D: Initial breakup of debris accumulation due to high water and loss of structural integrity of debris. E: Scouring of channel banks and bottom resulting in the formation of side and channel snags.

The "Great Raft" was a complex series of debris jams caused by clumping massive numbers of logs during floods. The history of a typical blockage in the Red River is reconstructed in Fig. 2 from accounts by PAXTON (1829), LONG (1841), ABERT (1845), and WOODRUFF (1873). During high discharge debris jammed the width of the river commonly at a point bar or other channel constriction (Fig. 2 a), and ponded upstream water.

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Subsequent storms extended the accumulation while finer debris (leaves, shrubbery, small branches) filled interstices. Eventually debris weight and waterlogging forced wood toward the bottom. Within 2—5 years, upstream ponding slowed current velocity, promoted sedimentation and raised the water level into riparian areas, where alluvium was deposited along the banks (Fig. 2 b). Rising water level, filling of interstitial spaces, and sinking to the channel bottom partially sealed the dam and forced a new outlet for discharge. Due to low relief of the valley floor the new outlet was generally the channel of an upstream tributary. Rise of water elevation in the river reversed the direction of flow in the tributary, and diverted upstream discharge onto forested riparian areas. Water flooded the lowland forest, filling newly formed lakes until a new outlet was found. Aggradation of the main channel and diversion of discharge continued (Fig. 2 b and c). Upstream accumulations of debris, particularly near outlets, resulted in a continuous series of dams upstream of the raft. Tributary channels enlarged due to major diversion of water from the main channel. Alluvial deposition along margins of the debris dam promoted invasion of riparian trees and effectively narrowed the channel (Fig. 2 c and Fig. 3). In riparian areas, inundated trees died and were eventually blown over. At high flows trees were swept from the lake, contributing to further channel blockage. After 80—150 years partially decomposed wood was swept from the jam during a flood (Fig. 2 d). Exposed alluvium was scoured and previously buried wood projected into the water column forming channel snags. The channel gradually widened and deepened. As it widened, shoreline trees toppled into the river forming side snags. The channel was gradually restored as additional decomposed wood was swept away (Fig. 2 e). Little additional accumulation was made, since upstream debris dams effectively intercepted drift. Riparian zone lakes remained as long as water was diverted from the main channel during floods. The time required for main channel restoration is unknown, since most of the downstream raft formation was at this stage when anthropogenic impacts became a dominant channel process.

raft formation

Prior to their destruction, debris dams accumulated in the Red River over a period of approximately 375 years. The great raft affected 390—480 km of main channel, and instantaneous blockage was approximately 225 km. Veatch (1906) estimated that the raft originated near Alexandria, La. in the late 1400's. Approximately 375 years later the raft terminated 5 km south of the Louisiana — Arkansas border. An approximate chronology of debris clearance operations is presented in Table 1, and a more extensive history of the raft is presented in Harris & Veatch (1899).

Persistence of individual debris dams was related to the size and species composition of log debris. Cottonwood (*Populus* sp.) was generally considered the major dam component (Paxton 1829; Marcy 1854; Woodruff 1872; Straser 1879). Other more recalcitrant trees: oak (*Quercus* spp.), elm (*Ulmus americana*), sweet gum (*Liquidambar* sp.), sycamore (*Platanus* sp.), cypress (*Taxodium* sp.), and cedar were reported by Paxton (1829), Abert (1845), Marcy (1854), and Straser (1879). Marcy (1854) also reported elm (*Ulmus americana*) and oak (*Quercus macrocarpa*) growing along the banks of Red River.

components

The longest logs in the raft were 30.0 m to 36.0 m and up to 1.75 m in diameter (Woodruff 1873; White 1885; Willard 1891 a). Benyaurd (1880) reported mean width and length of various debris types as follows: snags 0.6 m × 9.1 m (sample size 1210 pieces), drifting logs 0.5 m × 16.8 m (sample size 2229 pieces), and trees felled along the bank 0.6 m × 19.2 m (sample size 753 pieces). Willow (*Salix* sp.), despite its small size (< 0.25 m diameter, Woodruff 1872), effectively filled interstices between larger debris,

Table 1. Chronology of anthropogenic modification of raft region 1833—1872.

Year	Activity	Source
1833	Seventy miles (113 km) of highly rotted wood was dislodged and floated away while an additional seventy miles remained. The exposed timber mass covered 33—50% of the total surface.	SHREVE (1834)
1836	Despite continuous debris removal, thirty-one miles (46 km) of organic debris remained, and seventeen miles (27 km) accumulated or reformed since the previous year.	SHREVE (1836)
1838	The debris accumulation was completely cleared. Approximately 700 m of newly formed raft were removed by unknown persons, but the channel immediately reclogged.	LONG (1841)
1839	Raft clearance operations were abandoned and Sewell's Canal was cut between Black Bayou and Red Bayou, for steamboat passage around the raft (Figs. 5 a, c).	COLLINS (1873)
1841	Three miles (4.4 km) of solid wood debris accumulated since 1836.	LONG (1841)
1841—44	Three miles (4.4 km) of debris was cleared by 1842 but immediately reclogged. Four miles (6.5 km) aggregate raft was removed in 1843 but the raft reclogged immediately (0.3 km). After additional accumulation and removal, 0.8 km remained in 1844 when the project was abandoned. Between May 10 and May 16, 1845, 2.75 km of large trees were added to the raft.	ABERT (1845)
1855	The raft had extended itself to 20 km. Canal and tributary modification were proposed to promote shipping around it. Two miles (3 km) of debris were removed. Channel improvements were made above Dooley's Bayou.	FULLER (1855)
1857	Drift refilled the cleared areas in the vicinity of Dutch John's Lake. A channel was cut through the lake for navigation. Massive reclogging of the channel resulted in abandonment of the project.	
1872	Raft length totaled 40 km; 9 km of actual wood debris. The channel was cleared using snag boats and explosives by 1873. Navigation was permanently established along the main channel.	WOODRUFF (1872, 1873)

colonized the dams and bound debris together with its extensive root network. ABERT (1845) noted, "Willow bars have encroached upon the channel the width of which in many places is too small to allow large trees to pass."

Limited available information indicates the mean rate of raft accumulation was $1.6\,km \cdot yr^{-1}$ prior to initial efforts at debris removal (Table 2), and $1.4\,km \cdot yr^{-1}$ thereafter for the longer records (FULLER 1855; HERVEY 1873; WOODRUFF 1873). Both extension at the head and retreat at the foot of the raft were episodic. Maximum accumulation was 8 km during a single extreme freshet (SHREVE 1836). Assuming a mean accumulation rate of $1.6\,km \cdot yr^{-1}$ and 225 km of instantaneous blockage, typical turnover time is estimated at 140 years. Turnover time is defined as the loss of structural integrity due to decomposition, rather than total biological mineralization of wood tissue.

Effects on riparian areas

Organic debris blockage of the Red River's main channel impacted adjacent shoreline areas in two ways: (1) by flooding large tracts of riparian forest and grassland, and (2) by modifying drainage patterns of major tributaries. Flooding was the primary impact prior

Table 2. Accumulatio

Years	Rate (km · y
1793—1828	1.6
1816—1828	1.6
1820—1838	1.6
1836	8.1
1839—1855	1.3
1841	6.4
1844—1845	1.6
1845	2.7
1855—1872	1.3
1858—1872	1.7
1866	3.2
1877	6.8
1889	4.8

Fig. 3. Debris blockag
of the Louisiana — Ar

Table 2. Accumulation rates of wood debris in the main channel of the Red River.

Years	Rate ($km \cdot yr^{-1}$)	Raft length (km)	Years	Reference	Remarks
		Prior to organic debris removal			
1793—1828	1.6	56.5	35 years	Paxton (1829)	Recollections of settlers
1816—1828	1.6	19.3	12 years	Paxton (1829)	
1820—1838	1.6	25.8	18 years	Long (1841)	
		After organic debris removal			
1836	8.1	8.1	1 year	Shreve (1836)	Single freshet
1839—1855	1.3	21.0	16 years	Fuller (1855)	
1841	6.4	6.4	1 year	Abert (1845)	
1844—1845	1.6	3.2	2 years	Abert (1845)	
1845	2.7	2.7	1 year	Abert (1845)	7-day-storm May 10—May 16, 1845
1855—1872	1.3	21.0	16 years	Woodruff (1873)	6 miles actual wood
1858—1872	1.7	24.2	14 years	Hervey (1873)	Appendix B to Woodruff (1873)
1866	3.2	3.2	1 year	Hervey (1873)	Appendix B of Woodruff (1873)
1877	6.8	6.8	1 year	Benyaurd (1877)	Cumulative total 9/76—4/77
1889	4.8	4.8	1 year	Willard (1889)	Includes 2.5 km jam of commercial logs

Fig. 3. Debris blockage in the main channel of Red River at low flow. Photo was taken 8 km south of the Louisiana — Arkansas border by R. B. Talfor (1873).

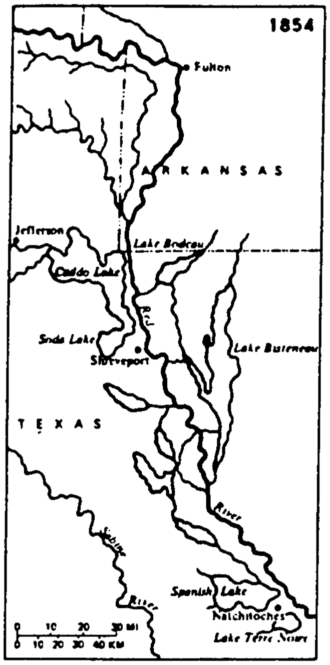

Fig. 4. Portion of the Red River Valley, between Natchitoches, La. and Fulton, Ak., redrawn from an original map by MARCY (1854). The map indicates the presence and location of major riparian lakes resulting from wood blockage in the main channel of Red River.

to debris removal while tributary modification was a major technical problem following clearance of organic debris. Riparian areas flooded between Natchitoches, La. and Shreveport, La. are illustrated in an early map of MARCY (1854) (Fig. 4). Along the east (right) bank lay Lake Bistaneau described on a map by SHREVE (1834) as a former cypress swamp filled with standing dead timber. To the north was Lake Bodcau described by PAXTON (1829) as a beautiful prairie in 1793 where immense herds of buffalo grazed. On the west bank, the Caddo Lake complex described later as Cross Lake, Sodo Lake, Ferry Lake, and Clear Lake, was filled with standing dead timber.

The amount and state of decay of standing dead timber provide important clues to the age of riparian lakes, and turnover time of wood debris. PAXTON (1829) noted that lakes near the head of the raft contained more standing dead timber than those further downstream such as Lake Terre Noire, which had only remnants of debris to indicate its previous forested condition. He noted that standing timber toward the center of the lake had few limbs, while that along the margins retained small branches indicating recent inundation. Assuming a raft accumulation rate of $1.3\,\mathrm{km} \cdot \mathrm{year}^{-1}$, HARRIS & VEATCH (1899) estimated the Caddo Lake complex began filling in 1777. Using $1.6\,\mathrm{km} \cdot \mathrm{year}^{-1}$ (Table 2) as the accumulation rate, initial inundation is estimated at 1789. Using the latter rate, Lake Terre Noire began filling in 1679. Thus approximately 150 years elapsed before PAXTON's (1829) observations, indicating the decay time of debris in lakes was similar to that in the channel. Photographs showing partially decayed stumps in Ferry Lake (Caddo Lake Complex) by VEATCH (1906) indicate decomposition time is in excess of 116 years.

A pictorial representation of change in lake size between 1838—1901 is presented on Fig. 5 for riparian lakes between Shreveport and the Arkansas border. At the time of the

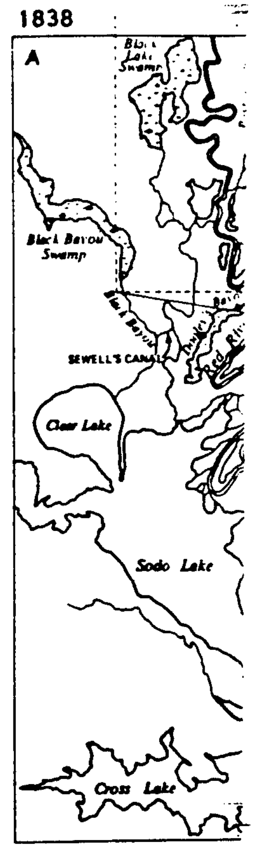

Fig. 5. Maps of the raft re
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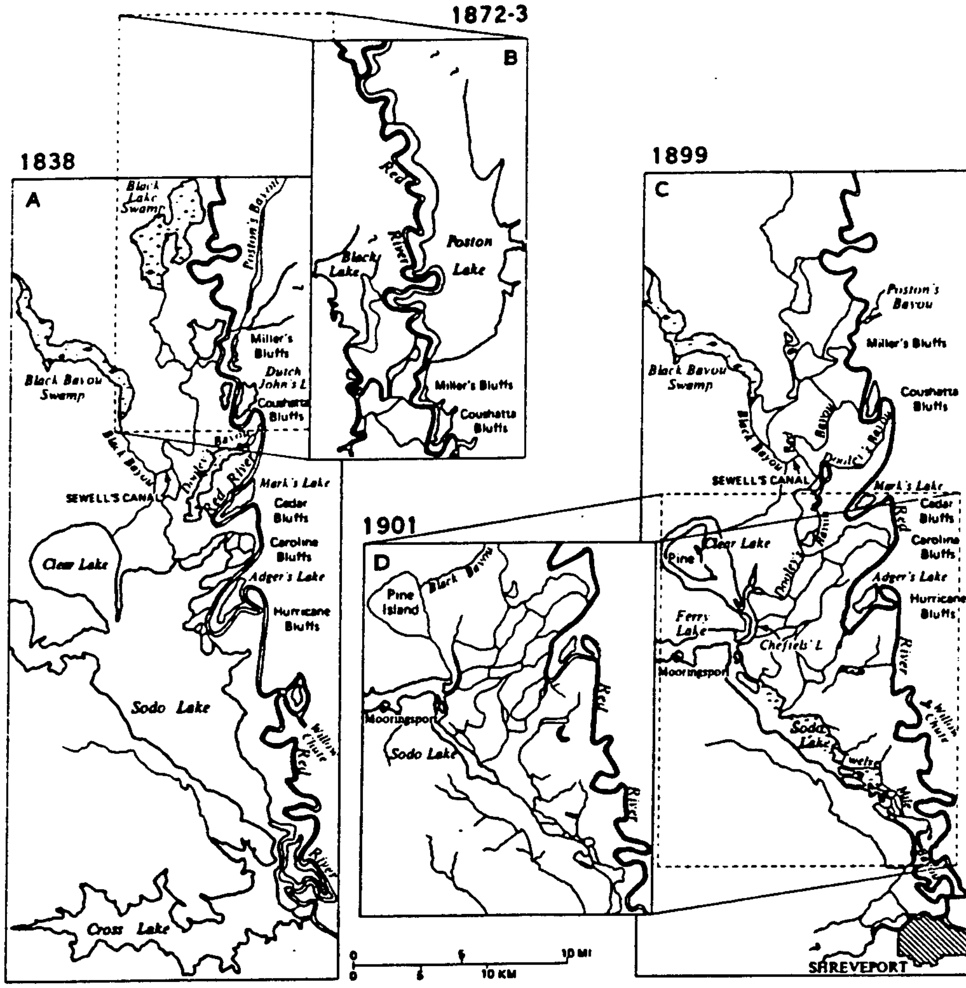

Fig. 5. Maps of the raft region during four periods between 1838 and 1901 redrawn to uniform scale from HARRIS & VEATCH (1899) and VEATCH (1906). Original maps were compiled from data in public land surveys. Lakes designated (?) indicate minimal areal coverage, since exact shoreline could not be determined.

earliest land surveys (1838) Sodo Lake, Cross Lake, Ferry Lake, and Clear Lake (Fig. 5 a) existed approximately 50 years. Sodo Lake was near its largest size in 1840 (LONG 1841) and partially drained even before raft removal. Noteworthy is the proximity of Sodo Lake to the river's main channel and to Cross Lake. Just south of the Arkansas border on the west bank lies a lowland area identified as Black Lake Swamp, and on the east bank is Poston's Bayou. By 1872, wood accumulated north of Poston's Bayou resulting in inundation of Black Lake Swamp (Fig. 5 b). On the east bank, water flooded around Miller's Bluff forming Poston's Lake. Severe reduction in lake size occurred after debris was cleared and the channel opened in 1873. Twenty-five years later (Fig. 5 c), Black Swamp Lake had drained completely and was no longer designated swampland. Poston's Lake had also drained completely. Clear Lake partially drained and Pine Island emerged (Fig.

Table 3. Approximate areal coverage (km^2) of riparian zone lakes formed as a result of organic debris clogging in the Red River.

Lake	Year				
	1839[1]	1855[3]	1872[2]	1899[1]	1901[2]
Sodo Lake	64.2[4]	27.35	–[5]	7.6	4.5
Cheftels' Lake	–	5.14	–	1.6	–
Clear Lake	20.5	–	–	10.6	drained
Cross Lake	46.5	–	–	–	–
Poston's Lake	prelake	–	60.0	drained	drained
Black Swamp Lake	13.2	–	22.6	drained	drained

[1] Calculated from maps by Harris & Veatch (1899).
[2] Calculated from maps by Veatch (1906).
[3] Calculated from a map by Fuller (1855).
[4] Includes inundated area which later became Cheftel's (Shiftail) Lake.
[5] No data available.

5 c). The northwest reach of Sodo Lake was now called Cheftels' Lake. By 1899 Sodo Lake almost completely drained; and the distance between the river channel and lake shore increased to approximately 6.5 km. Cross Lake and Sodo Lake, nearly connected in 1839, were 9.7 km apart. In a map drawn in 1901 (Fig. 5 d), Cheftel's Lake was reduced to a narrow channel. Ferry Lake drained partially but was retained by construction of a dam. Cross Lake was also dammed.

Available data on areal coverage of the raft lakes is presented in Table 3. Estimates are approximate, since lake size fluctuated seasonally with river discharge. Maximum known size of Sodo Lake (including Cheftels' Lake) was 64 km^2. It was reduced to 32.5 km^2 by 1855, to 8.4 km^2 by 1899 and to 4.5 km^2 by 1901. Clear Lake drained to half its maximum size by 1899 and was almost completely drained by 1901 (Veatch 1906). Poston's Lake did not exist before 1855, since organic debris accumulation extended only to Coushatta Bluffs. Black Swamp Lake probably filled shortly thereafter by blockage of Red Bayou, since it appears on a 1861 map of alluvial deposits (Humphreys & Abbot 1861) while Poston's Lake does not. Thus Poston's Lake filled sometime between 1861—1868 and was deep enough to serve as a steamboat route between 1868—1872.

The time a lake existed prior to raft removal determined the time required for drainage. Poston's Lake, the last formed, was among the first to drain, although it was large relative to most riparian lakes. This was because the original outlet channel remained after inundation while in older lakes the outlet channel filled with wood debris and sediment. Drainage was reestablished either by natural recutting of the old channel or cutting an entirely new channel.

None of the lakes drained rapidly because constant reconsolidation of wood debris diverted water into them during floods. Poston's Lake and Black Swamp Lake, while drained completely by 1899, still appeared on a crude map drawn by Willard in 1891. On the same map Sodo Lake appeared as a long narrow channel between Ferry Lake and Cross Lake, and Pine Island was present in Clear Lake. In addition, many of the older lakes between Shreveport and Natitoches appeared in 1891, more than 50 years after the first removal of debris (Table 1). For the oldest lakes this was 200—300 years after initial inundation. Thus once the raft lakes formed and the outlet channel filled, some became nearly permanent features of the riparian landscape. Ironically, arable farmland lost to

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the "destroying angel" and restored by removal of wood debris was relost the following century by impounding many of these valleys for flood control, navigation, and recreation.

Impacts on tributary streams

diversion of water from main channel into tributaries

Debris dams blocked the main river impounded water many kilometers upstream which slowed current velocity, settled alluvium, and entrained large organic debris. As the channel bottom was aggraded tributaries which formerly drained into the main channel reversed their flow, becoming outlets from the river and inlets to the lakes discussed above. Tributary channels rapidly enlarged due to water diversion from the main channel, and in some instances entirely new channels were formed. Rapid bayou enlargement south of the later settlement of Shreveport was described in a letter written in 1825 by A. Hanscom (in Mercer 1827): "In descending the Red River, the route at present pursued leaves the river and enters Willow Bayou, the head of which is about 6 miles (9.7 km) in a straight line from the head of the raft. This bayou is deep and rapid; it has increased in size at least one-half within the last three years; in consequence of the raft having caused an elevation of the river at the head of it."

The proportion of main channel discharge diverted into tributary channels was large. Long (1841) estimated that half the discharge of the Red River was directed from the main channel at high water by Red Bayou, Dooley's Bayou and New Bayou above the head of the raft and Cheftels' Bayou below the raft. Some 10 miles and 22 miles downstream, Willow Chute and Benoit's Bayou diverted half the remaining water to Lakes Bodcau and Bisteneau, respectively (Fig. 4). Long estimated 75 % of the water was restored approximately 18 miles further down via outlets from Cross Lake (Cross Lake Bayou) and Sodo Lake (Caddo or 12 Mile Bayou). Just south of Shreveport, however, two-thirds of the water was rediverted into a large bayou, Bayou Pierre. A similar account with slightly different estimates of main channel diversion was given by Abert (1845). This enlargement of former tributary channels in conjunction with the raft lakes, formed a network which permitted steamboat passage around the wood obstructed main channel, and resulted in the building of canals to enhance navigation (Table 1).

A final impact of wood on tributary channels was their use as a disposal site. The purpose of raft clearance was to improve navigation by maximizing flow to the main channel. Shreve (1834) wrote, "When the work was begun the current was very slack, not to exceed one-fourth of a mile an hour; it has now increased throughout the whole distance to at least three miles per hour; that result was produced by the removal of the mass of timber and depositing it in the numerous outlets and bayous that pass out from the right bank of the river and from thence into the lakes and swamps ... One of these bayous, the Pass a' Gola was as large as the river, it has been filled full of timber from the raft, a distance of about four miles (6.5 km) and so drove in by running a steamboat frequently against the timber as it was conveyed that near all the water was immediately forced down the old bed of the river."

Similarly, during final removal between 1872—1873 much of the log debris floated off was passed into Tones Bayou, an enlarged tributary 30 km south of Shreveport. An insignificant stream 10 years earlier, by 1876 it carried off three-quarters of the low flow discharge of Red River (Benyaurd 1877). Closure of the channel failed when the drift was washed downstream in a subsequent flood. Tones Bayou was permanently closed in

1899. There are accounts of numerous other tributary closures and levee projects to restore low flow navigation (Willard 1893, 1895).

Impacts on the main channel

Major direct effects of wood on the main river channel were bed aggradation and channel narrowing. Channel blockage by wood debris was estimated between 33 and 50 % of the total raft area (Shreve 1834). Even in pools behind major debris dams the bottom of the channel was almost completely covered by sunken logs. In conjunction with high sediment loads the bed continually rose until the actual channel flowed along a ridge above the lowlands.

Estimates of channel narrowing by wood debris and sediment is indicated in Table 4. Above and below the reach affected by the raft, river width ranged between 180—230 m. By comparison, channel width in the impacted area varied from 27—46 m during the raft period. By 1886 channel width increased to 76—90 m in the raft area above Shreveport although the minimum width at certain sites was still 40 m (Willard 1887). By 1888 channel width increased to 122 m in the vicinity of, and south of Shreveport (Willard 1888).

Debris removal and channel recovery

Debris removal resulted in immediate local channel scouring. Total restoration, however, took decades. Shreve (1834) reported, "On the passage down I made particular examinations later at several places which I had taken the depth of water when working up and found that the current produced by removal of the raft had washed out the deposit from the bottom of the river a depth of at least ten feet (3.1 m)." A second indirect estimate of channel aggradation was a phenomenon called "Dawn Stumps". After removal of wood debris above Shreveport, several hundred upright logs project almost 2 m above low water when they were cut off near the water level. The following year, 1886,

Table 4. Width of the Red River during the period of channel blockage by wood debris.

Year	Width (m)	Location	Source
		A. Upstream and downstream of impacted channel	
1841	229	Above Arkansas border	Long (1841)
1845	183	Arkansas–Louisiana state border	Abert (1845)
1886	180–215	Below raft impacted area	Willard (1886)
1887	183	Above raft impacted area (88 miles Fulton to Long Prairie, Ark.)	Willard (1887)
		B. Channel width in raft impacted reach	
1833	40	Raft area below Shreveport	Shreve (1834)
1841	27–46	Foot of Shreve raft south of Shreveport	Long (1841)
1845	37	Hurricane Bluffs	Abert (1845)
1855	37	Between Hurricane Bluffs and Shreveport	Fuller (1855)
1876	38	Raft region	Howell (1876)[1]
1886	76	Entire raft area average	Willard (1887)
1888	122	Shreveport to 30 km south	Willard (1888)
1892	122	Cross Bayou at Shreveport	Willard (1893 b)

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at the same water stage they projected an additional 1.5 m above the water when permanently removed by explosives (WILLARD 1888).

Prior to removal of debris in 1873, a crew under WOODRUFF (1872) established bench marks from which low water elevation was determined. In 1893 WILLARD reported locating several of the original bench marks, and estimated that the low water line had fallen approximately 15 ft (4.7 m) at the head of the raft to approximately 3 ft (1.0 m) at Shreveport. By 1895 numerous wrecks of steamboats lost during the raft period, and uncovered by continual scouring, were exposed at low water. Until 1893 these wrecks were not reported as obstructions and were, in fact, rarely seen (WILLARD 1895). In 1908 a survey in the raft area above Shreveport reported that the channel bottom had lowered by as much as 7.6 m compared to 1873 (SMITH 1909), indicating continued response to the aggradation of the raft period nearly 40 years later.

Wood debris which either remained or was newly exposed by scouring, intermittently blocked the channel up to 40 years later. Debris blocks consisted of two types, channel jams which completely closed the channel, and side jams anchored to the banks but extending into the river. The frequency of channel jams decreased rapidly following channel clearance (Fig. 6). However, in almost every year, up to 1909, the channel was blocked at some time by organic debris. Channel jams after 1880 often consisted of significant quantitites of cut logs which broke away from commercial timber rafts.

Side jams were often formed in eddies where tributaries entered the river. They were considered a hazard but did not usually curtail commerce. Unlike channel jams, there was no consistent pattern in either development or removal of side jams. The highest numbers removed were 172 in 1889, and 167 in 1897.

Large logs projecting through the channel bottom (channel snags) or from the bank (side snags) were exposed by scour, and subsequently removed as navigation hazards. Since scour is related to discharge volume, the number of snags removed annually was likewise related to floods (Fig. 7 a, b). The magnitude of annual snag removal was highly variable due to several years of record stage height within 20 years of raft clearance. These record stage heights partially resulted from eliminating lakes as a buffer for upstream discharge. Water previously diverted into the lowland lakes flushed through the deepening channel and exposed previously buried debris. In addition, riparian timber which invaded the channel during the aggradation phase was swept into the river at high flow as banks caved in, forming shore snags (Fig. 7 b). WILLARD (1889) states, "As an instance of the temporary character of the improvements of this stream, I state that in

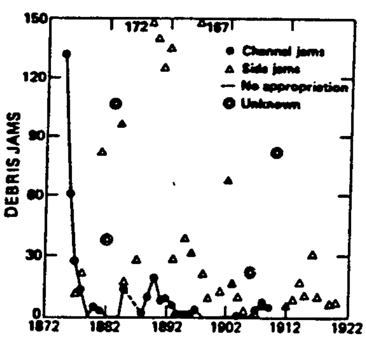

Fig. 6. Number of debris jams removed annually from Red River. Data were compiled from the Annual Report of the Chief of Engineers, U.S. War Department for each year between 1872 and 1920.

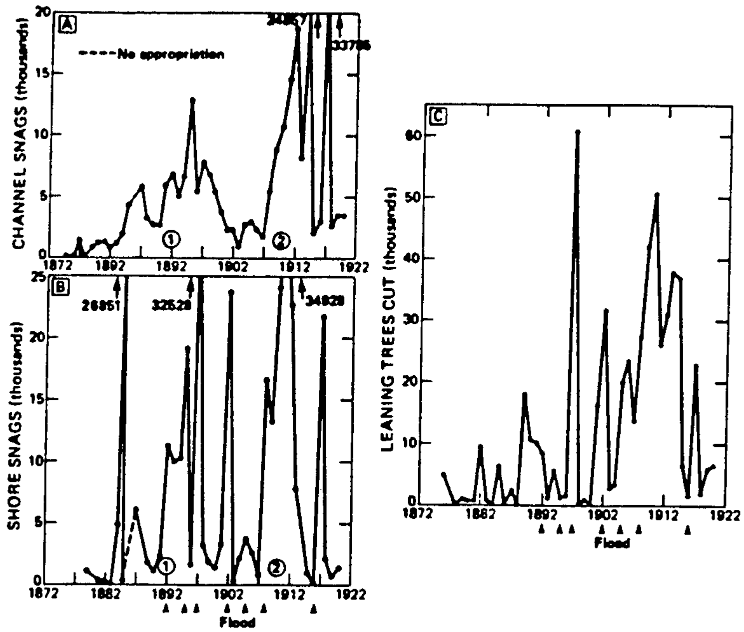

Fig. 7. Annual removal of (A) channel snags, (B) side snags, and (C) leaning trees cut along the banks of Red River. Data were compiled from the Annual Report of the Chief of Engineers, U.S. War Department for each year between 1872 and 1920. Circled 1 indicates construction date of a large levee; circled 2 indicates the beginning of continuous dredging.

March (1889) on the way up, the Megs (a snag boat) cut all trees in the Cottage Home Bend (about 145 km below Shreveport) for a distance of 20 feet (6.1 m), but on the return found that the bend had caved in so rapidly that the portion cleared had gone into the river." Twenty years after raft removal the channel was described by WILLARD (1893) as follows:

> "A channel was opened through this obstruction (rafts) in 1873 and operations since, aided by the action of the current, have secured greater width and depth throughout the entire reach with a channel way constantly widening and scouring until little water is diverted from the river proper except at flood stages …
>
> The removal of snags and other obstructions should be continued for many years. In the old raft region above and below Shreveport, sunken logs and stumps are scouring loose continually, and are a constant source of danger to low-water navigation. Others, thoroughly water-logged, form bars, impassable at low stages. The banks of the upper river, for hundreds of miles, are covered with a heavy growth of timber, which is caving and sliding into the river continually, and during high stages in the amount of drift is enormous. In the raft region above Shreveport, jams form in a few hours, often acres in extent, and require prompt removal before the water falls. Caving banks leave dangerous shore snags projecting far into the river, which should be cut after every rise and fall."

A large levee project begun in 1892 further channelized the river bed, and in conjunction with high water in 1892 and 1895, resulted in a significant increase in the number of both shore and channel snags. After 1897 massive treecutting was initiated to prevent leaning trees from falling into the channel (Fig. 7c). By 1904 MARSHALL wrote following a large flood:

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"Within the last fifteen years the changes which have taken place in Red River below the hills near the Louisiana — Arkansas State line down to the hills at Grand Ecore have been quite remarkable. Where formerly the river was narrow and tortuous, with low banks lined with timber, now is a wide open channel with long bends, large sand bars, high banks, and cleared fields. Of course it is all due to clearing of the country, confinement of the waters by levees, cut-offs, and removal of sunken logs from the river bed. It is the first step toward regulating and improving the river."

The process of channel scouring and widening after raft removal which made navigation safe at high water made it worse during low discharge as water spread out over the newly widened channel (MARSHALL 1904). To improve low flow navigation, a self propelled dredge was constructed in 1908. Systematic dredging in the years following may have contributed to the large number of channel snags, side snags, and leaning trees removed between 1908 and 1920 (Fig. 7 a, b, c), finally eliminating the role of wood in the channel. After 1920 the number of cut snags and timber were no longer reported by the Corps of Engineers. By then the river had assumed overall channel characteristics which today might be considered typical of a pristine lowland river.

It is impossible to know if debris impacts of equal intensity occurred in previous ages in the Red River Valley, or how far upstream the "Great Raft" would have extended if had it not been removed. In the alluvial strata of bluffs forming the valley margins north of Shreveport, COLLINS (1873) found evidence of previous wood deposition. He wrote, "The bluffs upon which the city (Shreveport) is built rise to 100 feet (30 m) ... and are stratified red clay containing large quantitites of fossil wood, with soft sandstone below and the same blue clay shale found ... in the bed of the river."

The interaction between riparian habitats and the river channel was no doubt greater in the Red River Valley than most lowland rivers. This is why its history was partially recorded. Nonetheless, wood debris was important in other major rivers including the Mississippi. In 1874 SAMUEL CLEMENS (MARK TWAIN 1883) notes in his *Life on the Mississippi*, "the peril from snags is not what it once was. The governments's snag boats go patrolling up and down in these matter of fact days, pulling the river's teeth; they have rooted out all the old clusters which made many localities so formidable; and they allow no new ones to collect." Once no new wood debris was allowed to collect, the relationship between the river channel and bankside communities diminished. Fluvial ecologists should give some thought to the history of their study areas since it is within this altered environment that stream ecology is currently conducted. Thus recent findings of a habitat role for wood debris in small forested drainages may not be a fluvial anomaly. Rather these drainages may more nearly represent microcosms of once widespread but now nearly extinct riverine habitats.

Summary

Historical records were reviewed to estimate the impact of wood debris on a 400—500 km reach of the Red River, Louisiana, U. S. A. In the primal condition the banks consisted of unstable alluvial deposits easily eroded during floods. Sediment and riparian trees from eroded banks formed organic debris dams which blocked the channel and promoted channel aggradation. Over a period >375 years wood debris dams formed in series. The longest instantaneous length of impacted channel was 225 km. The average rate of channel blockage was 1.3—1.6 km · year^{-1} between 1793—1876. Maximum debris accumulation recorded in a single flood was 8.1 km. Exposed wood covered 80—120 km of channel. Debris dams remained in place 80—150 years.

Wood debris impacted adjacent riparian areas by flooding forests and forming a series of large lakes. Under natural conditions lakes could become nearly permanent features of the riparian land-

scape if tributary channels filled with alluvium and organic debris. After removal of organic debris the most recently formed lakes drained over a period of approximately 30 years. Impoundment of water in the main river channel reversed the direction of flow in many tributary streams, especially at high discharge. Flow reversal in tributaries resulted in channel enlargement and diversion of one-half to three-quarters of the river's discharge adjacent to riparian lowlands. Wood debris reduced the river's width from approximately 185 m to approximately 40 m, and aggraded the river bed a maximum of 7 m. Tributary channels were dammed or filled with organic debris, and the river was permanently opened to navigation in 1873. Restoration of full channel flow exposed previously buried logs and eroded forested banks. By 1904, seventy years of debris dams and snag removal, levee projects, dredging and cutting bankside trees resulted in a cleared, wide, meandering channel, which might today be mistaken as typical of a pristine lowland river.

References

ABERT, J. J., 1845: Report of the Secretary of War, in answer to a resolution of the 18th December, in relation to removal of the raft in Red River in Louisiana. — Report 26, 29th Congress (Senate), 1st session, 13 pp.

ANDERSON, N. H., SEDELL, J. R., ROBERTS, L. M. & TRISKA, F. J., 1978: The role of aquatic invertebrates in processing wood debris in coniferous forest streams. — *Amer. Midl. Nat.* 100: 64—82.

BENYAURD, W. H., 1876: Removal of raft in Red River, Louisiana. Appendix K3. — Annual Report, Chief of Engineers, 44th Congress (House of Representatives), 2nd Session, Ex. Doc. 1, Part 2, 2: 596—599.

— 1877: Removal of raft and closing Tone's Bayou, Louisiana. Appendix L3. — Annual Report, Chief of Engineers, 45th Congress, 2nd Session, Ex. Doc. 1, Part 2, 2: 480—488.

— 1880: Improvement of upper Red River from Fulton to Head of the raft. Appendix 05. — Annual Report of the Chief of Engineers, 46th Congress (House of Representatives), 3rd session, Ex. Doc. 1, Part 2, 2: 1304—1305.

BILBY, R. E., 1981: Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. — *Ecology* 62: 1234—1243.

BILBY, R. E. & LIKENS, G. E., 1980: Importance of organic debris dams in the structure and function of stream ecosystems. — *Ecology* 61: 1107—1113.

BUCKLEY, B. & TRISKA, F. J., 1978: Presence and ecological role of nitrogen fixing bacteria associated with wood decay in streams. — *Verh. Internat. Verein. Limnol.* 20: 1333—1339.

BUSTARD, D. R. & NARVER, D. W., 1975: Aspects of the winter ecology of juvenile coho salmon (*Onconhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). — *J. Fish. Res. Board Can.* 32: 667—680.

CHRISTENSEN, O., 1977: Estimation of standing crop and turnover of dead wood in a Danish oak forest. — *Oikos* 28: 177—186.

COLLINS, H. C., 1873: Geological notes of assistant H. C. COLLINS. In: Survey of the Red River raft region Louisiana; Cypress Bayou, Texas; and Tone's Bayou, Louisiana, Appendix Q9A. — Annual Report, Chief of Engineers, 43rd Congress, Ex. Doc. 1, Part 2, 2: 653—664.

FULLER, C. A., 1855: Col. FULLER's survey of Red River. — 33rd Congress (House of Representatives), 2nd Session, Ex. Doc. 90, 6 pp.

GRIER, C. C. & LOGAN, R. S., 1977: Old-growth *Pseudotsuga menziesii* of a western Oregon watershed: Biomass distribution and production budgets. — *Ecol. Monogr.* 44: 373—400.

HARRIS, G. D. & VEATCH, A. C., 1899: A preliminary report on the geology of Louisiana, Part V. — Louisiana Geol. Survey, 354 pp.

HEEDE, B. H., 1972: Influences of a forest on the hydrologic geometry of two mountain streams. — *Water Resour. Bull.* 8: 523—530.

HERVEY, C. M., 1873: Letter to E. A. WOODRUFF, February 22, 1872. In: Survey of the Red River raft region Louisiana; Cypress Bayou, Texas; and Tone's Bayou, Louisiana. Appendix Q9B. — Annual Report, Chief of Engineers, 43rd Congress, Ex. Doc. 1, Part 2, 2: 664—665.

HOLLE, C. W., 1950: Status of federal projects in Red River basin under jurisdiction of the Corps of Engineers. — In: Information on the Arkansas-White-Red Basins Interagency Committee and Corps of Engineers, Corps of Engineers, Southwest Div. Dallas, Tex., 9 pp.

HUMPHREYS, A. A. & ABBOT, L
River. — Professional P
Co. Philadelphia, Pa., 45

KELLER, E. A. & SWANSON, F. J
processes. — *Earth Surfa*

KELLER, E. A. & TALLY, T., 19
cesses in the coastal red
Annual Geomorphology S

LONG, S. H., 1841: Report fro
from the Senate, a rep
(Senate), 1st Session, 23 p

MAC MILLAN, P. C., MEANS, J. I
decomposition in an old

MARCY, R. B., 1854: Explorati
ton, D. C., 309 pp.

MARSHALL, H. M., 1904: Repo
River Louisiana, Arkan
Chief of Engineers, VI,

MARTIEN, R. F., 1978: Water
sources Techn. Report N
of Public Works. Baton

MERCER, C. F., 1827: Navigati
whom was referred a m
the appropriation of a s
of Red River. — Report

MINCKLEY, W. L. & RINNE, J.
review. — *Desert Plants.*

NAIMAN, R. J. & SEDELL, J. F
Oregon. — *Arch. Hydro*

PAXTON, J., 1829: Letter from
Delegate to the Congre
River. — Report 78, 20t

Red River Basin Coordinating
siana, Oklahoma, and T
Interior and Bureau of F

SEDELL, J. R., EVEREST, F. H. &
Proc. of the Society of Am
Society of Amer. Fores

SEDELL, J. R. & LUCHESSA, K.
enhancement. — In: AR
tion of Aquatic Habitat
thesda, Md.

SEDELL, J. R. & TRISKA, F. J.,
streams. — In: *Logging*
Or., 10 pp.

SHREVE, H. M., 1834: Raft o
spondence of the superi
ment No. 98, 23rd Con

— 1836: Message from the
on the progress of the i
sion, Senate, 3 pp.

SMITH, C. S., 1909: Improvem
Appendix V1. — Annu

STRASZER, J., 1879: Report of
Red River Louisiana. A
gress (House of Represe

Humphreys, A. A. & Abbot, L. H., 1861: Report upon the physics and hydraulics of the Mississippi River. — Professional Paper No. 4, Corps of Topographic Engineers. J. B. Lippincott and Co. Philadelphia, Pa., 456 pp.

Keller, E. A. & Swanson, F. J., 1979: Effect of large organic material on channel form and fluvial processes. — *Earth Surface Processes* 4: 361—380.

Keller, E. A. & Tally, T., 1979: Effects of large organic debris on channel form and fluvial processes in the coastal redwood environment. — In: Rhodes, D. D. & Williams, G. P., *Tenth Annual Geomorphology Symposium*: 169—197. Kendall/Hunt Pub. Co. Dubuque, Iowa.

Long, S. H., 1841: Report from the Secretary of War transmitting, in compliance with a resolution from the Senate, a report on improvement of Red River. — Report 64, 27th Congress (Senate), 1st Session, 23 pp.

Mac Millan, P. C., Means, J. E., Hawk, G. M., Cromack, K., Jr. & Fogel, R., 1977. Douglas-fir log decomposition in an old-growth Douglas-fir forest. — *Northwest Science* (abstr.): p. 13.

Marcy, R. B., 1854: Exploration of the Red River in the year 1852. — U.S. War Dept. Washington, D. C., 309 pp.

Marshall, H. M., 1904: Report of H. M. Marshall, Assistant Engineer. In: Improvement of Red River Louisiana, Arkansas, Texas and Indian Territory. Appendix V1. — Annual Report, Chief of Engineers, VI, Part 2: 2035—2037.

Martien, R. F., 1978: Water quality characteristics of the Red River in Louisiana. — Water Resources Techn. Report No. 16. Louisiana Dept. of Transportation and Development, Office of Public Works. Baton Rouge, La., 32 pp.

Mercer, C. F., 1827: Navigation of Red River. Report: The Committee on Roads and Canals, to whom was referred a memorial of the General Assembly of the Territory of Arkansas asking the appropriation of a sum of money for the removal of certain obstructions in the navigation of Red River. — Report 96, 19th Congress (House of Representatives), 8 pp.

Minckley, W. L. & Rinne, J. N., in press: Large organic debris in hot desert streams: A historical review. — *Desert Plants*.

Naiman, R. J. & Sedell, J. R., 1979: Benthic organic matter as a function of stream order in Oregon. — *Arch. Hydrobiol.* 87: 404—422.

Paxton, J., 1829: Letter from D. Joseph Paxton, of Hempstead County to the Hon. A. H. Sevier, Delegate to the Congress from the Territory of Arkansas in relation to the raft of Red River. — Report 78, 20th Congress, 2nd Session, 18 pp.

Red River Basin Coordinating Committee, 1968: Red River below Denison Dam: Arkansas, Louisiana, Oklahoma, and Texas Comprehensive Basin Study. — U.S. Dept. Agriculture, Dept. Interior and Bureau of Reclamation.

Sedell, J. R., Everest, F. H. & Swanson, F. J., 1981: Fish habitat and streamside management. — In: *Proc. of the Society of American Foresters*, Annual Meeting (September 27—30, 1981): 244—255. Society of Amer. Foresters, Bethesda, Md.

Sedell, J. R. & Luchessa, K. J., 1982: Using the historical record as an aid to salmonid habitat enhancement. — In: Armantrout, N. B., ed., *Proc. of a Symposium on Acquisition and Utilization of Aquatic Habitat Inventroy Information*: 210—223. West. Div. Amer. Fish. Soc. Bethesda, Md.

Sedell, J. R. & Triska, F. J., 1977: Biological consequences of large organic debris in Northwest streams. — In: *Logging debris in streams workshop*, 1977. Oregon State University, Corvallis, Or., 10 pp.

Shreve, H. M., 1834: Raft of Red River. Letter from the Secretary of War, transmitting correspondence of the superintendent of the work of clearing away the raft of Red River. — Document No. 98, 23rd Congress, 1st session (House of Representatives), 13 pp.

— 1836: Message from the President of the United States, with report from the Secretary of War, on the progress of the improvement of Red River. — Document 197, 24th Congress, 1st Session, Senate, 3 pp.

Smith, C. S., 1909: Improvement of Red River, Louisiana and Arkansas, below Fulton, Arkansas. Appendix V1. — Annual Report, Chief of Engineers, Part 2: 1547—1553.

Straszer, J., 1879: Report of Mr. Justin Straszer. In: Removing snags and other obstructions from Red River Louisiana. Appendix L4. — Annual Report of the Chief of Engineers, 46th Congress (House of Representatives), 2nd Session, Ex. Doc. 1, Part 2, 2: 962—964.

Swanson, F. J., Lienkaemper, G. W. & Sedell, J. R., 1976: History, physical effects, and management implications of large organic debris in western Oregon streams. — Gen. Tech. Rep. PNW 56. Portland, Or., USDA For. Serv., Pac. Northwest For. and Range Exp. Sta., 15 pp.

Swift, M. J., Healey, I. N., Hibberd, J. K., Sykes, J. M., Bampoe, V. & Nesbitt, M. E., 1976: The decomposition of branch wood in the canopy and floor of a mixed deciduous woodland. — *Oecologia* 16: 139—149.

Triska, F. J. & Cromack, K., Jr., 1981: The role of wood debris in forests and streams. — In: Waring, R. H., ed., *Forests: Fresh Perspectives from Ecosystem Analysis*: 171—190. Oregon State Univ. Press, Corvallis, Or.

Triska, F. J., Sedell, J. R. & Gregory, S. V., 1982: Coniferous forest streams. — In: Edmonds, R. L., ed., *Analysis of Coniferous Forest Ecosystems in the Western United States*: 292—332. Hutchinson Ross Publ. Co., Stroudsburg, Pa.

Twain, M., 1883: *Life on the Mississippi*. — James R. Osgood and Co., Boston, Mass., 624 pp.

Veatch, A. C., 1906: Geology and underground water resources of northern Louisiana and southern Arkansas. — *U. S. Geol. Survey Professional Paper* 46, 422 pp.

White, E. F., 1885: Report of Captain E. F. White. In: Improvement of the Red River, and of certain rivers in the states of Louisiana, Arkansas, Mississippi and Tennessee tributary to the Mississippi — Water Guages on the Mississippi and its principal tributaries. Appendix U. — Annual Report, Chief of Engineers, 49th Congress (House of Representatives), 1st Session, Ex. Doc. 1, Part 2, 2: 1480—1481.

Willard, J. H., 1887: Improvement of Red River, Louisiana and Arkansas. Appendix U1. — Annual Report, Chief of Engineers, 50th Congress (House of Representatives), 1st Session, Ex. Doc. 1, Part 2, 2: 1440—1451.

— 1888: Improvement of Red River, Louisiana and Arkansas. Appendix U1. — Annual Report, Chief of Engineers, 50th Congress (House of Representatives), 2nd Session, Ex. Doc. 1, Part 2, 2: 1331—1343.

— 1889: Improvement of Red River, Louisiana and Arkansas. Appendix W1. — Annual Report, Chief of Engineers, 51st Congress (House of Representatives), 1st Session, Ex. Doc. 1, Part 2, 2: 1584—1595.

— 1891 a: Survey of Red River to Fulton, Arkansas, to Atchafalaya River: Progess Report. Appendix V. Report of Captain Willard. — Annual Report, Chief of Engineers, 52nd Congress (House of Representatives), 1st Session, Ex. Doc. 1, Part 2, 2: 1954—1959.

— 1891 b: Improvement of Red River, Louisiana and Arkansas. Appendix V1. — Annual Report, Chief of Engineers, 52nd Congress (House of Representatives), 1st Session, Ex. Doc. 1, Part 2, 2: 1446—1450.

— 1893 a: Western rivers: Improvement of certain rivers and waterways in Louisiana, Texas, Arkansas, Mississippi, and Tennessee tributary to the Mississippi River; Water guages on the Mississippi and principal tributaries. — Annual Report, Chief of Engineers, 53rd Congress (House of Representatives), Ex. Doc. 1, Part 2, 2: 258—260.

— 1893 b: Improvement of Red River, Louisiana and Arkansas. Appendix V1. — Annual Report, Chief of Engineers, 53rd Congress (House of Representatives), Ex. Doc. 2, Part 2, 2: 1901—1999.

— 1895: Improvement of Red River, Louisiana and Arkansas. Appendix U1. — Annual Report, Chief of Engineers, 54th Congress, 1st Session (House of Representatives), Ex. Doc. 2, 2: 1848—1855.

Woodruff, E. A., 1872: Letter from the Secretary of War, Communicating in obedience to law, a report of the examination and survey of Red River from its mouth to a point above Shreveport, Louisiana. — 42nd Congress (Senate), 2nd Session, Ex. Doc. 71, 8 pp.

— 1873: Survey of the Red River raft region Louisiana; Cypress Bayou, Texas; and Tone's Bayou, Louisiana. Appendix Q9. — Annual Report, Chief of Engineers, 43rd Congress, Ex. Doc. 1, Part 2, 2: 635—651.

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Size distribution anc matter (FPOM) from

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As one of the major functiona tion of organic inputs has receivec for processing of coarse particu (Kaushik & Hynes 1968; Cummin & Klug 1976; Triska & Cromac of dissolved organic matter (DC organic matter (FPOM). This i diameter, occurs as a result of ph ding invertebrates, and by the m

One of the important microb phomycete fungi (Suberkropp & degrade cellulose and hemicellulo cells. With this enzymatic capab skeletonize leaf litter, and in the (Suberkropp & Klug 1980).

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AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS, VOL. 2, 145-163 (1992)

Effects of large woody debris removal on physical characteristics of a sand-bed river

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ABSTRACT

1. Removal of large woody debris (LWD) is one of the most widely practised stream alterations, particularly in sand-bed rivers of the south-eastern USA. Selective removal of LWD has been proposed as an alternative to orthodox non-selective clearing in order to conserve ecological resources, but methods for comparing hydraulic and environmental effects of selective and non-selective removal have not been developed. Conservation of stream habitats requires quantification of LWD removal impacts on physical habitat.

2. Physical characteristics of straightened, sand-bed reaches of the South Fork Obion River in western Tennessee, USA that were rich in LWD were compared with those in similar reaches where debris had recently been removed using selective removal guidelines.

3. The mean volume of LWD per unit water volume was 0.0545 in the uncleared reaches, but nearly 60% lower (0.0225) in the cleared reach.

4. A simple technique for predicting hydraulic roughness in channels with varying amounts of LWD was developed. Hydraulic roughness, as measured by the Darcy-Weisbach friction factor, was about 400% greater in uncleared reaches at base flow but declined to a level about 35% greater than for the cleared reaches at higher flows. Predicted friction factors were within 35% of measured friction factors at higher flows.

5. Physical habitat diversity in this channelized sand-bed stream was strongly related to the density of LWD. Flow conditions in the uncleared reaches were more heterogeneous than in the cleared reach, especially at low flow. At low flow, uncleared reaches tended to be shallower, have lower velocities, slightly finer bed material, and more heterogeneous conditions overall. Shannon indices based on depth and velocity were an average of 48% higher in uncleared reaches.

6. Bed sediments underneath and immediately adjacent to LWD formations were finer and contained more organic matter than sediments distant from LWD. However, when all bed samples were considered, organic content was positively correlated with median grain size.

INTRODUCTION

Large woody debris (LWD) has been the subject of increasing scientific interest in recent years due to its influence on stream morphology and fluvial processes (Bilby, 1984; Gregory *et al.*, 1985; Beschta and Platts, 1986; Cherry and Beschta, 1989; Gippel, 1989), macroinvertebrates (Anderson *et al.*, 1978; Benke *et al.*, 1985; Benke and Parsons, 1990), fish (Hickman, 1975) and ecosystem dynamics (Harmon *et al.*, 1986; Hauer, 1989). Debris dams and other LWD formations retain leaf litter and other detritus in streams and allow

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processing by invertebrates (Prochzaka *et al.*, 1991). LWD accumulations are prominent features along most natural streams and may p[illegible]e substrate for most of the invertebrate biomass in sand-bed rivers, such as those common to the Coastal Plain of the south-eastern USA (Benke *et al.*, 1985) and the desert south-west of the USA (Minckley and Rinne, 1985). Cover, depth and velocity patterns associated with LWD formations are essential elements of fish habitats (Hortle and Lake, 1983; Angermeier and Karr, 1984).

Frequently, LWD is removed from stream channels to increase conveyance, control erosion, or reduce navigation hazard. LWD removal may be the most common form of stream habitat modification in the USA. Deleterious effects of debris removal ('clearing and snagging') have been at least qualitatively appreciated for many years (Little, 1973; Marzolf, 1978; Yorke, 1978; Bilby, 1980). Guidelines for selective removal of LWD formations (International Association of Fish and Wildlife Agencies (IAFWA), 1983; Shields and Nunnally, 1984) have been proposed to reduce adverse effects of LWD removal on stream habitats, but the effectiveness of the guideline approaches as conservation practices have not been evaluated. Due to the ubiquity of LWD removal projects, use of these guidelines may become one of the most widely practised stream habitat conservation strategies. When planning and designing LWD removal projects, stream managers must balance 'engineering' (e.g. flood control, drainage or navigation) and habitat conservation objectives. Quantitative, rational techniques for striking this balance are currently lacking.

The purpose of this paper is to describe effects of selective LWD removal on channel conveyance and physical aquatic habitats of a sand-bed river, with an overall objective of providing a basis for impact assessment and conservation strategy development for similar rivers and streams. This objective required development of a technique for predicting changes in Darcy friction factors due to LWD removal. Stream properties which were of interest included LWD density, which was treated as the primary independent variable, Darcy friction factor, aquatic habitat diversity, and bed sediment size and carbon content. Debris density, hydraulic roughness (Darcy friction factor), and velocity distributions were measured for reaches ~ 1.5 km long at low, moderate, and near-bankfull stages, and aquatic habitat (depth, velocity, and substrate distributions) was sampled at base flow.

PREDICTION OF EFFECTS OF LWD REMOVAL ON FRICTION FACTOR

Planning and design of an LWD removal project that will be performed using selective removal guidelines should include quantification of the physical effects of incremental LWD removal. In particular, reliable yet inexpensive methods for predicting the variation of channel friction factor with LWD density are needed for planning-level hydraulic analyses. Published friction factors for severely obstructed channels are three to four times larger than for those free of significant LWD (Shields and Nunnally, 1984). Few observations of friction factor before and after LWD removal are available; reported reductions range from 10 to 80% (US Engineer Office, Mobile, Alabama, 1940; Gippel, 1989). Techniques currently employed for determining hydraulic effects of LWD removal rely on estimation and engineering judgement (Chow, 1959; Barnes, 1967). Engineers select friction factors based on experience by comparing the channel in question to photographs or tabular descriptions in standard references such as Chow or Barnes. These photographs generally depict either channels with virtually no LWD or with evidently high (but unspecified) LWD densities.

Petryk and Bosmajian (1975) presented an equation for predicting coefficients (Manning's n) for open channels where vegetation plays a major role in the flow resistance (e.g. broad, heavily vegetated floodplains, roadside drainage ditches with thick, tall vegetation, and canals choked with aquatic vegetation). The equation was derived from first principles by assuming that flow conditions are uniform and that the approach velocity to each plant stem is equal to the mean velocity. By applying reasoning similar to that of Petryk and Bosmajian to uniform steady flow through a straight channel reach where LWD plays a major role in flow resistance, the total friction factor can be expressed as

$$f_t = f_b + f_d \tag{1}$$

where

f_t = total Darcy–Weisbach friction factor

f_b = boundary friction factor excluding LWD effects, and

f_d = friction factor due to LWD.

The boundary friction factor f_b can be estimated using curves provided by Lovera and Kennedy (1969) and Alam and Kennedy (1969) or other standard methods. The friction factor due to LWD, f_d, may be determined by expressing the energy lost per unit channel length due to debris as the result of drag on a series of solid obstructions (Petryk and Bosmajian, 1975):

$$h_{Ld} = f_d(L/4R)(V^2/2g) \tag{2}$$

$$= K_d(V^2/2g) \tag{3}$$

$$= C_d D_A L(V^2/2g) \tag{4}$$

which implies that

$$f_d = 4RC_d D_A \tag{5}$$

where

h_{Ld} = head loss, due to debris [L]

L = reach length [L]

R = mean hydraulic radius, assumed equal to depth [L]

V = mean water velocity [LT^{-1}]

g = acceleration of gravity [LT^{-2}]

K_d = dimensionless loss coefficient

C_d = drag coefficient for LWD, assumed equal to 1.0 (Petryk and Bosmajian, 1975), and

D_A = roughness concentration due to LWD [L^{-1}].

D_A may be thought of as the average roughness concentration (Li and Shen, 1973) per unit length. It is given by

$$D_A = \frac{\sum_{i=1}^{n} A_i}{BRL} \tag{6}$$

where

A_i = cross-sectional area of ith debris formation in plane normal to flow, and
B = average water-surface width.

STUDY SITE AND DISTURBANCE HISTORY

The South Fork Obion River is part of a 13 000 km² agricultural watershed that is tributary to the left descending bank of the Mississippi River in western Tennessee. Regional geology is characterized by unconsolidated and highly erosive Quaternary formations. Wisconsin loess dominates surficial geology, and there are no bedrock controls of stream base level. Watershed relief is low, and the narrow floodplains were

wetlands traversed by sinuous channels of low gradient prior to initial channelization and drainage. Straightening and dredging of channels throughout the basin have occurred periodically since about 1900 (Simon and Hupp, 1986; Simon, 1989).

The study area was located between River Kilometers (RKs) 37.1 and 45.8 of the South Fork Obion River (Figure 1). Upstream drainage area was about 927 km^2. The sand-bed channel was straight, and cross-sections were trapezoidal and uniform with top widths ranging from 18 to 23 m and maximum depths from 4 to 5 m. At the outset of the study, banks were steep but stable, and were composed of clay and silt. At base flow, water surface widths were 12 to 17 m, and mid-channel depths ranged from 0.6 to 1.5 m. Photographs of the study area are presented by Smith *et al.* (in press).

The study area was well suited for our research. The disturbance history and present condition of the South Fork Obion River are typical of many streams in the south-eastern United States. The channel was flanked by hardwood forests. Riparian species found along adjacent and downstream reaches in the same watershed included boxelder (*Acer negundo*), river birch (*Betula nigra*), sycamore (*Platanus occidentalis*), bald cypress (*Taxodium distichum*) and various species of oaks (*Quercus* spp.) and elms (*Ulmus* spp.)(Hupp, 1986; Simon and Hupp, 1987). Tree ages ranged from 25 to 45 years (Simon and Hupp, 1987). An LWD removal project was under way at the time, and selective removal guidelines were employed. Prior to clearing, LWD formations occupying more than one-fifth of the cross section were common. Hydrologic variations were damped due to ponding upstream of a major LWD formation that completely blocked the channel upstream of the study area, creating near-steady flow conditions that facilitated dilution gauging. Study reaches (Figure 1) were free of major tributary inflows. The straight channel planform simplified partitioning hydraulic roughness into components due to LWD and the channel boundary.

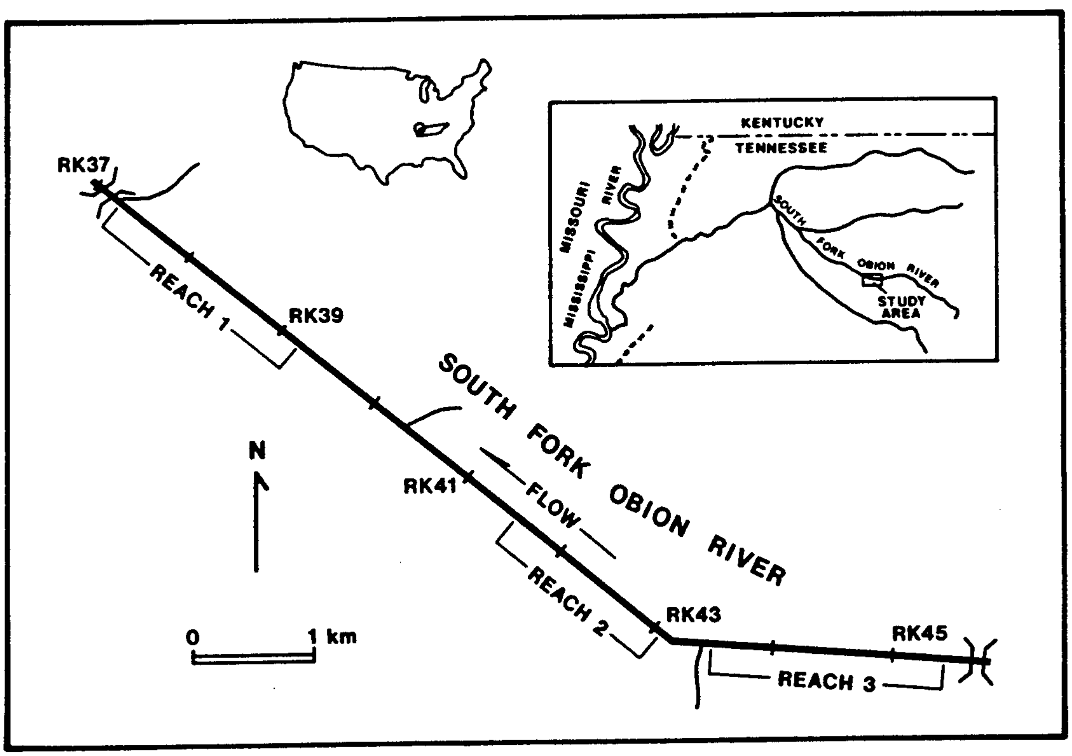

Figure 1. Location of study reaches. Data were collected between October 1989 and August 1990. Reach 1 was cleared in the fall of 1989 just prior to study initiation. Reach 2 was cleared in June–July 1990. Reach 3 was cleared in May 1990.

The study channel was initially straightened in the early 1900s. Additional dredging occurred from the mouth to RK 8.3 and from RKs 13.3 to 15.4 in 1967 and 1969 respectively (Barstow, 1971; Smith and Badenhop, 1975). LWD removal was performed just downstream from the study area (RKs 9.6 to 36.8) between 1976 and 1978 (personal communication, Andrew Simon, US Geological Survey, Nashville, Tennessee). From 1978 to 1985 channel modification, including LWD removal, was halted by litigation throughout the Obion-Forked Deer Basin. After 1985, channel modifications were performed in compliance with guidelines similar to IAFWA (1983) (Governor's West Tennessee Natural Resources Task Force, 1985).

Instability of reaches downstream of the study area following the 1967–69 channelization has been described in some detail by Simon (1989) and Simon and Hupp (1986), but the study area was relatively stable during this period. Cross-section plots and specific gauge records for locations downstream of the study area indicated headward-progressing bed degradation (personal communication, Andrew Simon, US Geological Survey, Nashville, Tennessee). About 1 m of degradation occurred between RKs 26.9 and 30.7 between 1978 and 1983 and about 0.6 m of lowering occurred at the lower end of the study area (RK 37.1) between 1980 and 1983. However, cross-section surveys taken at the upper end of the study area (RK 45.6) in 1969, 1979 and 1983 showed no evidence of degradation. At the outset of this study, channel banks in the study area were quite stable, and old disposal piles from the turn-of-the-century channel work were still evident along the edges of the main channel in 1990. Upstream of the study area, specific gauge analysis for RK 55.2 showed a slight aggradation of 0.4 m between 1967 and 1981.

An LWD removal project was in progress within the study area while data were being collected. Project design and construction were according to the aforementioned guidelines. The work was performed by a crew of seven men using a D-3 bulldozer with a cable and winch, chainsaws, and a small flat bottom boat with motor. Work was limited to removal of trees and LWD from the bottom and banks of the channel. Logs embedded in the channel were not removed if they were aligned with the flow. No rooted trees, whether alive or dead, were cut unless they were leaning at an angle of 20° or more off vertical or unless they had severely undercut or damaged root systems. Access and material disposal were limited to one side of the channel to minimize disturbance of riparian habitat. The LWD was placed in windrows parallel to the channel in a manner that prevented re-entry into the channel. No channel excavation (i.e. sediment removal) was performed. Cost for the project was about US\$29700 km^{-1}.

DATA COLLECTION

Density of LWD

Several investigators have described labour-intensive techniques for determining stream LWD density (e.g. Wallace and Benke, 1984; Robison and Beschta, 1990). These methods require measurement of the diameter of each piece of LWD within a channel reach or a large fraction of the LWD within a reach. Less rigorous methods were described by Hauer (1989), who measured the dimensions of LWD formations in 10 m channel segments (five segments per site) and by Zimmer and Bachman (1976), who reported the number of debris formations per unit channel length without regard to formation size. Due to our study objectives and funding constraints, we required a method that would be suitable for determining the LWD density in reaches long enough for measurement of macroscale hydraulic roughness (say > 1 km) and easy enough to require only several man-hours per km of channel. Due to the dense floodplain vegetation in the study area, the channel was only partially visible from the air and access along the top of banks was very limited. Therefore, a method for estimating LWD density based upon a visual survey from within the channel was developed.

LWD data were obtained for three straight reaches, each approximately 1.5 km long (Figure 1) at stages ranging from near-bankfull to base flow. Nine LWD surveys were performed prior to LWD removal, and

six surveys were performed after LWD removal. LWD surveys consisted of counting all LWD formations with an area in the plane of the water surface larger than about 1 m^2. In order to minimize errors due to observer subjectivity, the same person performed all surveys for the study. Each formation was assigned to one of nine size categories. Size classifications were based on visual estimates of the maximum length of each LWD formation below the plane of the water surface in directions perpendicular and parallel to the primary flow direction. Size categories were based on the reach mean water surface width, B. The following intervals were used for size classification: in the direction perpendicular to the primary flow, each formation was classified as smaller than $0.25B$, more than $0.25B$ but less than $0.5B$, or more than $0.5B$. In the direction parallel to flow, each formation was classified as smaller than $0.5B$, more than $0.5B$ but less than B, or more than B. Since there were three possible size scores in each of two dimensions, there were a total of nine size categories.

Data from LWD surveys were used to compute roughness concentration D_A (as defined by equation 6 above), dimensionless density (LWD volume/unit water volume), LWD volume per unit streambed area, and LWD frequency (formations/unit channel length). It was assumed that the vertical submerged dimension of each LWD formation was equal to the reach mean depth. Therefore for the ith LWD formation, A_i was set equal to the midpoint of the size interval for the direction perpendicular to flow multiplied by the reach mean depth, R. For example, a formation measuring roughly $0.4B$ (perpendicular to flow) by $0.8B$ (parallel to flow) would have $A_i = 0.375BR$. Since $D_A = \Sigma A_i/(BRL)$, BR may be dropped from both numerator and denominator. Dimensionless density (volume of LWD per unit water volume) and volume of LWD per unit streambed area were computed by dividing $\Sigma\ V_i$ by BRL and BL, respectively, where V_i = submerged volume of the ith debris formation = mean depth multiplied by the product of the midpoints of the two size intervals. For the example previously given, $V_i = R(0.375B \times 0.75B)$. Trees and stumps on banks that projected into flow were counted, and their contribution to roughness concentration (A_i) and LWD density (V_i) were computed using estimated submerged lengths and means of samples of their diameters measured using tree calipers.

Stream hydraulic characteristics

Dilution gauging techniques were used to obtain discharge, time-of-travel frequency distributions, and Darcy friction factors for the three 1.5 km reaches (Figure 1). Nine slug-injection fluorescent dye tests were conducted during flows ranging from 3.9–41.3 $m^3 s^{-1}$ in uncleared reaches, and six tests were run in cleared reaches during flows ranging from 3.6–53.2 $m^3 s^{-1}$. Dosage requirements, preparation of the dye standards, and procedures for calibration of the fluorometer were determined using standard procedures (Hubbard *et al.*, 1982). Tests were conducted at the downstream reach first and then proceeded upstream. Emergent bars and riffles were not observed during dye tests. An appropriate volume of Rhodamine WT dye was instantaneously released at the upper end of each reach from a small boat. A flow-through fluorometer was set up at the lower end of the reach and used to measure dye concentration with time. During each dye test, water surface elevations were recorded using temporary staff gauges that were installed at the upstream and downstream ends of each reach, and water surface widths were measured at five to 12 regularly spaced cross-sections. Dye curves were used to compute discharge, and mean depth was computed by dividing the discharge by mean width multiplied by reach length. Mean velocity was computed by dividing reach length by mean travel time. Water surface slope was determined from gauge readings and reach length, and Darcy friction factors were determined from a uniform flow equation.

Sediment and organic matter retention

Bilby and Likens (1980) and Coleman and Dahm (1990) noted the importance of LWD formations in trapping and retention of organic matter (which provides a basis for some food chains) and sediments finer than sand. In sand-bed rivers fine, cohesive sediments support much higher levels of invertebrate

biomass density than adjacent sands (Shields and Milhous, 1992). LWD influence on channel retentive capability was measured by converting normalized dye curves (which are time-of-travel distributions) to velocity distributions by dividing reach length by travel times. The 90 percentile velocities, which represent the maximum velocity for the slowest-moving 10% of the dye cloud, were compared for cleared and uncleared reaches for a range of flows. In addition, samples of bed material were also collected from five to eight cross-sectional transects in each of the three reaches and returned to the laboratory for sieve analysis (both fall and spring) and determination of organic content (combustible matter) (spring only). Four to five samples were collected at equidistant points at each transect in the fall and from the channel centre line (in the more homogeneous cleared reach) and three (in the uncleared reaches) equidistant points at each transect in the spring. The presence or absence of cover (LWD formations) adjacent to bed sample collection points was recorded. Single-classification model II analyses of variance (ANOVA) were performed for sample median bed material size (D_{50}) and carbon content using reaches and cover as treatments, and two-way unequal ANOVA was performed using reach and cover as classifications.

Aquatic habitat

An approach similar to one described by Gorman and Karr (1978) was used to characterize physical aquatic habitats at low flow. Five to eight cross-sectional transects at water-surface-width intervals were established in each of the three 1.5 km study reaches at locations judged to be typical of the entire reach. Velocity, depth, substrate (surficial bed material), and cover were measured or classified at points spaced at 0.9 m intervals along each transect. Depths were determined using wading rods and sounding lines, while velocities were measured at 0.6 depth using Price and Marsh-McBirney current meters. Data were collected by wading or, when depths exceeded about 1.2 m, from small boats. Predominant bed material type was visually categorized as clay/silt, sand, gravel, leaf litter, or vegetation (five categories) at each measurement point in the field. The presence or absence of cover (two categories) was also noted for each point. Cover classifications were based on visual inspection of the spherical volume with 0.5 m of each measurement point. Points coinciding with or within 0.5 m of logs, log jams, undercut banks, or overhanging canopy were classified as 'with cover'. Spring data were collected from reach 1 after clearing and from reach 2 prior to clearing. Fall data were collected from reach 1 after clearing and from reaches 2 and 3 before clearing.

Means and standard deviations of depth and velocity were computed for cleared and uncleared reaches and for points with and without cover. Single-classification model II analyses of variance (ANOVA) were performed for depth and velocity data using reaches and cover as treatments, and two-way unequal ANOVA was performed using reach and cover as classifications. Shannon diversity indices (Gorman

Table 1. Scheme used to assign grid points to habitat types. Depth and velocity intervals for scores were based upon habitat requirements of regional fish fauna

Score	Depth (cm)	Velocity ($cm\,s^{-1}$)	Substrate
1	<5	<1	Clay/silt
2	5–20	1–5	Sand
3	20–50	5–20	Gravel
4	50–80	20–40	Leaf litter
5	80 or greater	40 or greater	Vegetation

Table 2. Comparison of measured large woody debris densities for uncleared and cleared reaches of the South Fork Obion River with published values for other streams

LWD density units	South Fork Obion River		From literature			
	Uncleared LWD density	Cleared LWD density	LWD density	Drainage area[c], km^2	Stream(s)	Reference
Roughness concentration, D_A km^{-1}	1.2–9.2	5.8–12.5	92–110	Unknown	Kaskaskia Mutual Dredged Channel, Illinois, USA	Petryk and Bosmajian (1975)
Formations/km channel	35–58	6–58	0.6–34.4	373–712	11 streams in Iowa, USA	Zimmer and Bachman (1976)
			148	7000	Ogeechee R, GA, USA	Wallace and Benke (1984)
m^3/ha stream bed	430–940	90–330	168	755	Black Creek, GA, USA	Wallace and Benke (1984)
m^3/ha stream bed			110	See note d below	Meyer's Br, SC, USA	Hauer (1989)
m^3/ha stream bed			2[a]	See note d below	Steel Cr, SC, USA	Hauer (1989)
m^3/m^3 water	0.0316–0.0869	0.0062–0.0405	0–0.233[b]	<716	Bunyip R., Victoria, Australia	Hortle and Lake (1982)

[a]LWD density depressed due to many years of flow augmentation by a thermal discharge.
[b]Reported as 'area of snags as % of total area'. Equivalent to our dimensionless density (m^3/m^3) since we assumed vertical dimension of LWD formations = mean depth.
[c]For comparison with our study site drainage area ~927 km^2.
[d]Meyer's Branch and Steel Creek are second order tributaries of a 91 km^2 catchment. They drain areas of nearly identical size.

and Karr, 1978; Magurran, 1988) were calculated for each of the three reaches using depth, velocity, and substrate data from the transects. For purposes of Shannon function computations, each sampled point was assigned a digital score based on the scheme in Table 1. The category boundaries in Table 1 are a modification of those proposed by Gorman and Karr (1978) based upon fish habitat preferences in similar-sized, disturbed, warmwater streams in the mid-southeastern United States (Shields and Hoover, 1991). Shannon indices were computed using combined digital scores for depth and velocity (25 possible categories) and depth, velocity, and substrate (125 possible categories). Shannon indices for cleared and uncleared reaches were compared using a two-tailed t-test for unpaired data (Magurran, 1988).

RESULTS

Density of LWD

LWD surveys performed prior to LWD removal yielded roughness concentration values that ranged from 5.8 to 12.5 km^{-1} and averaged 9.0 km^{-1}. Six surveys performed after LWD removal yielded roughness concentrations that ranged from 1.2 to 9.2 km^{-1} and averaged 4.7 km^{-1}. The ratio of LWD volume to water volume averaged 0.0545 for uncleared reaches and 0.0225 for cleared reaches. Density values for reaches 2 and 3 after clearing were higher than for reach 1 after clearing, primarily due to drift formations exposed by bed scour following construction. In general, LWD density decreased as stages increased from low- to mid-bank elevation, but remained relatively constant from mid-bank to near bankfull. However, LWD formations that were submerged deeply enough to be invisible were not counted. Therefore, LWD density may have been underestimated.

Although the method of measuring LWD density used in this study was crude, the resulting values were comparable to data presented by other workers for lowland streams in temperate, sub-humid environments (Table 2). The roughness concentration values by Petryk and Bosmajian (1975) were for a channel with more living vegetation on the bed and banks than our study reaches. Streams studied by Zimmer and Bachman (1976) were about twice as steep and had about half the watershed area of our study area. Wallace and Benke (1984) used various techniques that involved measuring dimensions of individual LWD stems; since we used LWD formation dimensions without regard for the openings between stems our values are higher. Values reported by Hauer (1989) and by Hortle and Lake (1982) may reflect the relatively small size of sampled areas: the former measured dimensions of individual LWD formations in ten 10 m reaches, and the latter reported the percentage of stream area occupied by snags on three occasions in six 50 m reaches. Harmon *et al.* (1986) presented an extensive tabulation of published values of coarse woody debris (> 10 cm diameter) in streams flowing through unmanaged temperate forests; values ranged from 2.5 to 4500 $m^3 ha^{-1}$. However, these data are almost entirely from upland or mountain streams draining watersheds smaller than 10 km^2, and many of the streams drain old-growth coniferous forests.

Measured friction factor

Measured Darcy–Weisbach friction factors ranged from 0.08 to 0.51 (Table 3) and were smaller for higher discharges (Figure 2). Decreasing flow resistance with increasing stage and discharge (within-bank flows)

Table 3. Means of measured values of Darcy–Weisbach friction factor (f), discharge (Q), and roughness concentration (D_A) for uncleared and cleared reaches of the South Fork Obion River

Flow condition	Uncleared			Cleared		
	f	Q (m^3s^{-1})	D_A (km^{-1})	f	Q (m^3s^{-1})	D_A (km^{-1})
Low	0.42	3.9	9.82	0.11	3.9	8.23
Mid-bank to near bankfull	0.17	32	7.07	0.11	33	1.83

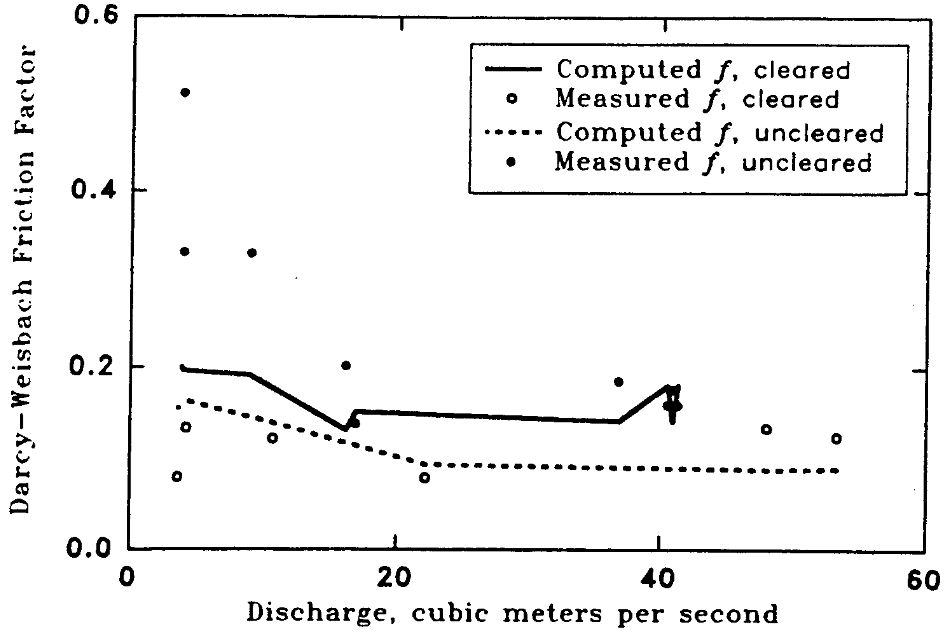

Figure 2. Measured and computed Darcy–Weisbach friction factors versus discharge for cleared and uncleared reaches. — computed f, cleared; ○ measured f, cleared; — computed f, uncleared; ● measured f, uncleared.

is in agreement with observations of Manning's n for larger sand-bed rivers (Chow, 1959), similar channels in the south-eastern United States (Fasken, 1963), and other channels with significant LWD (Gregory *et al.*, 1985; Gippel, 1989). Jarrett (1984) reported a similar trend for Manning's n in high-gradient streams, but noted that the trend reversed at highest stages when dense bank vegetation was partially submerged. Beven *et al.* (1979) reported a hundred-fold decrease in Darcy's f for a hundred-fold increase in discharge for a small, steep English stream.

LWD effects on f were most pronounced at low flow (Figure 2). Evidently, LWD promotes energy dissipation by forcing flow contraction and pool formation processes that decrease as flows increase. Additionally, flexible branches may be forced prone at higher flows (Kouwen and Unny, 1973). Friction factors for cleared and uncleared reaches converged at higher flows. At flows $> 10\,m^3 s^{-1}$, mean values of f for cleared ($n = 4$, mean $= 0.11$) and uncleared ($n = 6$, mean $= 0.17$) reaches were close but different at a confidence level of 99.93% (t-test for unequal variances; Mann-Whitney U test gave similar results). Assuming bed slope remained constant, the difference in mean values of f implies that LWD removal increased the amount of discharge conveyed by the channel at bankfull by about 25%. Similar observations of friction factor convergence at higher flows were reported by Hecht and Woyshner (1987) for Manning's n values for reaches of the Pajaro River in California with forested and riprapped banks. Young (1991) reported that artificial LWD (wooden dowels) inserted in a small laboratory flume caused stage increases of 0.1–10% at constant discharge and bed slope. Stage rise was an exponential function of $\Sigma A_i/(BR)$ (see equation 6 above for definition of variables). Since his model was a fixed-bed rectangular cross-section flume and represented near-bankfull flow past one or two LWD formations, direct comparison with our results is difficult.

Computed friction factor

Darcy–Weisbach friction factors computed using the procedure described above ranged from 0.09 to 0.20

Table 4. Means of computed values of Darcy-Weisbach friction factor, standard deviation of differences between computed and measured friction factors, and standard deviation of per cent difference between computed and measured values

Flow condition	Uncleared			Cleared		
	f	SD of error	SD % error	f	SD of error	SD % error
Low	0.20	—	—	0.16	—	—
Mid-bank to near bankfull	0.15	0.04	21	0.10	0.03	28

Standard deviations not shown for low flow since $n=2$ for uncleared and for cleared.

(Table 4). Computed values of f differed from measured values by -61 to $+101\%$ and were most accurate for mid- to near-bankfull stage conditions (for flows $\geqslant 10\ m^3s^{-1}$ errors ranged from -33 to $+19\%$ in cleared reaches and from -35 to $+12\%$ in uncleared reaches). Errors were larger from low flows because the method used to compute f accounts only for energy losses due to grain, bed form, and LWD roughness, but not local losses due to expansion and contraction which are increasingly important at low flow (Miller and Wenzel, 1985). Computed values were closer to measured values for cleared reaches (S.D. of errors = 0.045) than for uncleared reaches (S.D. of errors = 0.11).

Velocity distributions

Means and variances of velocity distributions derived by dividing reach lengths by dye cloud travel times increased with increasing discharge. During flows $\geqslant 18\ m^3s^{-1}$, a very small percentage of uncleared reach

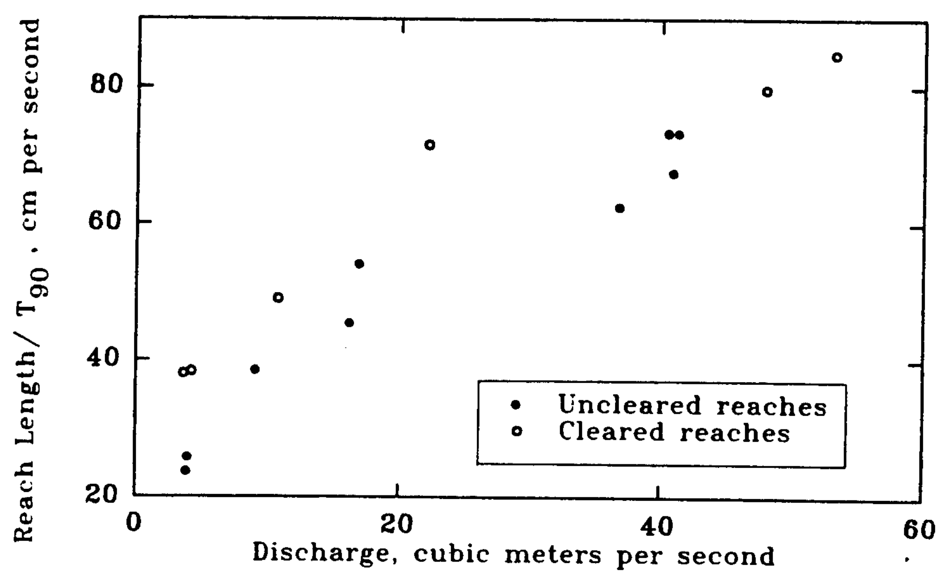

Figure 3. 90-percentile velocity versus discharge for cleared and uncleared reaches. The 90-percentile velocity is equal to the reach length divided by the time required for 90% of a slug injection of dye to pass through the reach (T_{90}). ● uncleared reaches; ○ cleared reaches.

velocities exceeded $1\ \mathrm{m\,s^{-1}}$, but more than half of the velocities in cleared reaches exceeded $1\ \mathrm{m\,s^{-1}}$. For approximately equivalent discharges, mean velocities were less for uncleared reaches. The velocity of the slowest-moving 10% of the dye cloud V_{90} was used as an indicator of the relative ability of cleared and uncleared reaches to trap and retain fine sediments and particulate organic matter. Not surprisingly, V_{90} was directly related to discharge (Figure 3). Uncleared reaches were more retentive at low flows but not at high flows. For the four measurements at flows approximately equal to $4\ \mathrm{m^3 s^{-1}}$, the two V_{90} values in the cleared reach were 50% greater than the two values for uncleared reaches (means of 38 and $25\ \mathrm{cm\,s^{-1}}$, see Figure 3). For discharges $>10\ \mathrm{m^3 s^{-1}}$, V_{90} for cleared reaches ($n=4$, mean $=71\ \mathrm{cm\,s^{-1}}$) was not significantly larger than for uncleared reaches ($n=6$, mean $=63\ \mathrm{cm\,s^{-1}}$) ($p=0.38$, t-test for unequal variances; $p=0.86$, Mann-Whitney U test). V_{90} was inversely related to measured Darcy–Weisbach friction factor ($r=-0.61$).

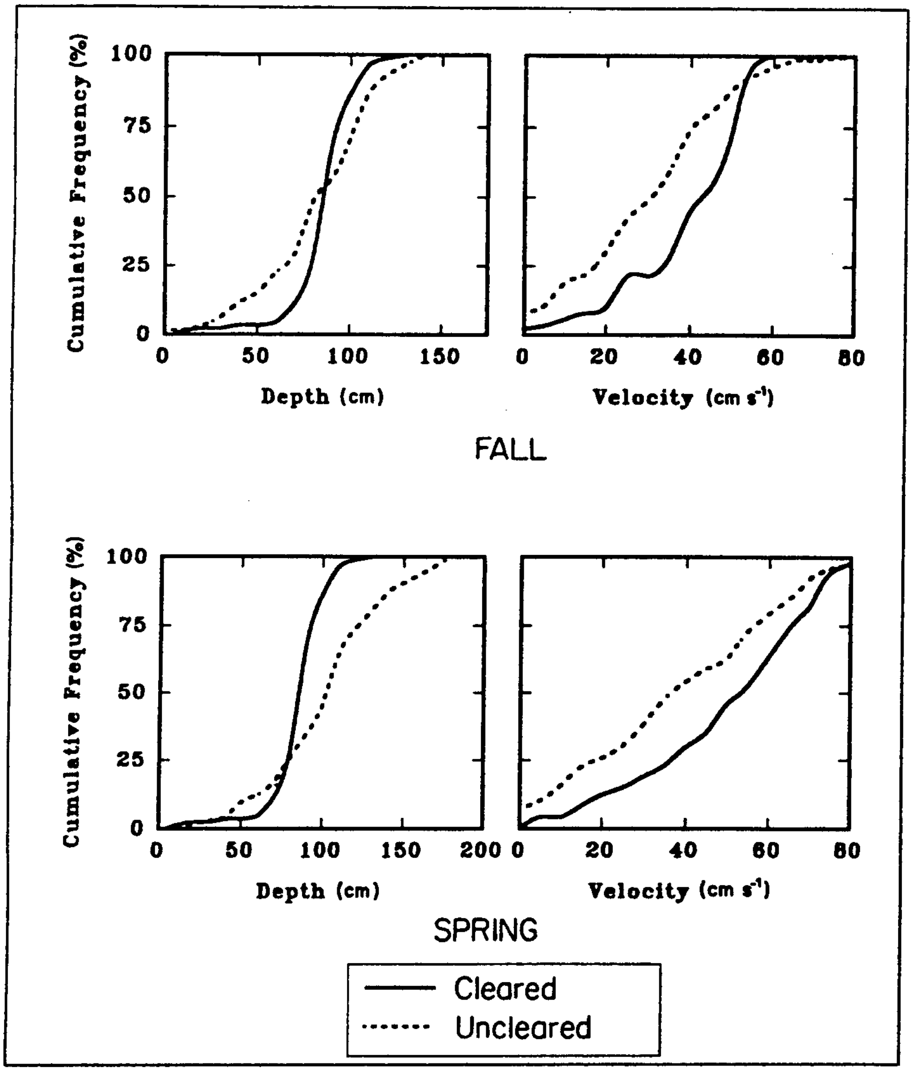

Figure 4. Cumulative frequency distributions for depth and velocity for data collected in October-November 1989 and May 1990 in reach 1 (cleared) and reaches 2 and 3 (uncleared). — cleared; ---- uncleared.

Table 5. Means and standard deviations of depth, velocity, and median bed sediment size for cleared and uncleared reaches of the South Fork Obion River.
ns = not sampled

A. Data grouped by 1.5 km study reach. Analysis of variance indicated reaches had significantly different depths, velocities and bed material sizes at the 99% confidence level with the exception of bed material in the fall

			Depth (cm)		Velocity ($cm\,s^{-1}$)		D_{50} (mm)		Per cent finer than sand		Per cent organic matter	
Season	Reach	Condition	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Fall	1	Cleared	84	17	39	14	0.59	0.18	ns	ns	ns	ns
	2	Uncleared	82	36	32	20	0.44	0.16	ns	ns	ns	ns
	3	Uncleared	93	37	26	13	0.27	0.11	ns	ns	ns	ns
Spring	1	Cleared	133	26	49	22	0.57	0.08	1.20	0.45	1.32	0.40
	2	Uncleared	102	34	37	24	0.44	0.18	4.83	11.59	1.11	0.75

B. Data points grouped based on cover presence within a 0.5 m radius. Analysis of variance indicated differences in depth and velocity were significant at the 99.9% confidence level. Fall median bed sizes were different at the 98% level; spring bed sizes were not significantly different

		Depth (cm)		Velocity ($cm\,s^{-1}$)		D_{50} (mm)		Per cent finer than sand		Per cent organic matter	
Season	Sampled points	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Fall	Without cover	94	27	39	13	0.47	0.19	ns	ns	ns	ns
	With cover	73	35	21	18	0.31	0.20	ns	ns	ns	ns
Spring	Without cover	119	32	44	34	0.50	0.12	ns	ns	ns	ns
	With cover	84	34	28	22	0.32	0.04	5.24	2.42	2.16	3.85

Physical habitat

Cross sections within cleared reaches were trapezoidal, and velocity patterns were symmetrical about the channel centreline. In contrast, data from uncleared reaches displayed considerable lateral variation in depth and velocity within sections and variation in width between sections. Uncleared reaches provided considerably more aquatic surface area with relatively shallow depth and reduced velocity (Figure 4). In the fall, only 22% of the points in the cleared reach had velocities less than $30\,\mathrm{cm\,s^{-1}}$, while 55% of the points in the uncleared reaches had velocities less than $30\,\mathrm{cm\,s^{-1}}$. The influence of debris on velocity persisted at higher stages in the spring, as 19 and 40% of the points in the cleared and uncleared reaches respectively had velocities less than $30\,\mathrm{cm\,s^{-1}}$. Uncleared reaches had greater mean widths than cleared reaches, which is consistent with continuity considerations.

As expected, cover was more common in uncleared reaches. In the fall, only 24% of the sampled points in the cleared reach had some type of cover, either small logs (11%) or undercut banks (12%), while 44% of the points in the uncleared reaches had some type of cover (small logs, log jams, undercut banks, or canopy). Only 8 and 22% of the points in the cleared and uncleared reaches, respectively, had cover in the spring, possibly because embedded logs were obscured by higher stages. Beds of all three reaches were sand: 92% of all substrate classifications were sand, but a few points in uncleared reaches were classified as clay/silt or vegetation.

Depth and velocity were subjected to two-way ANOVA using reaches (Table 5A) and cover (Table 5B) as treatments. Cover was classified as present or absent. Variation in depth and velocity due to reach and cover was statistically significant at the 99.99% confidence level. However, variations in depth and velocity due to interaction of reach and cover classification were not statistically significant, indicating that the local effects of remnant cover in cleared reaches were similar to cover effects in uncleared reaches. Evidently habitat characteristics near remnant LWD in cleared reaches were similar in quality to those in uncleared reaches. However, clearing greatly reduced the quantity of the low-velocity habitat created by LWD.

Bed composition

Bed material in all three reaches was sand but was finer in the uncleared reaches and at sampling points adjacent to cover (Table 5). Organic matter (as a percentage of dry weight) and median grain size were slightly higher in the cleared reach than in the uncleared reach, but these differences were not statistically significant. The mean percentage of sediment finer than sand size was four times greater in the uncleared reach than in the cleared reach (4.8 as opposed to 1.2%), but this difference was partially due to a single sample from the uncleared reach with an extremely high fines content (51%). Sediment samples collected from sampling points with cover had mean D_{50} values that were 56% higher, respectively, than points without cover. Organic content was positively correlated with median grain size ($r^2 = 0.585$, $p = 0.0001$), but not % fines ($r = 0.126$, $p = 0.46$). Conversely, Parker (1989) performed in-stream experiments with wire baskets filled with sediments coarser than the sands we studied (gravel, pebbles, cobbles, and mixtures) and found that the smallest substrate (gravel) collected the greatest quantity of fine (< 1 mm) organic matter.

Shannon indices

Shannon indices indicated higher levels of physical habitat diversity associated with LWD (Table 6). Fall indices based on depth, velocity, and substrate for uncleared reaches averaged 28% higher than for the cleared reach, but the index for uncleared reach 3 (1.79) was not significantly greater than the index for the cleared reach (1.60). The spring index (depth-velocity) for the uncleared reach was 80% higher than the depth-velocity index for the cleared reach. Fall depth-velocity Shannon indices were higher than spring depth-velocity indices, presumably because higher flows and stages in the spring drowned out the influence of roughness elements such as LWD on depths and velocities. Decreasing physical heterogeneity with increasing discharge was

Table 6. Shannon diversity indices (H') and number of habitat categories (S) observed in cleared and uncleared reaches of the South Fork Obion River. Diversity indices for reach 2 were different from indices for reaches 1 and 3 at the 98% confidence level in both fall and spring. Indices for reaches 1 and 3 were not significantly different

		Fall (DVSub)[a]		Fall (DV)[b]		Spring (DV)[b]	
Reach	Condition	H'	S	H'	S	H'	S
1	Cleared	1.60	13	1.49	11	0.95	7
2	Uncleared	2.29	20	2.04	15	1.79	14
3	Uncleared	1.79	21	1.61	13	—	—

[a]Based on depth, velocity, and substrate.
[b]Based on depth and velocity.

also indicated by dye test results (Figure 3). Physical habitat diversity was further quantified by counting the number of different habitat categories recorded for each study reach. This quantity, termed 'habitat richness' is found in columns headed with an 'S' in Table 6. Fall habitat richness values for uncleared reaches based on depth, velocity, and substrate averaged 21 out of a possible maximum of 125, while cleared reach richness was only 13. Habitat types corresponding to categories with velocities less than 1 $cm s^{-1}$ were generally present in uncleared reaches, but absent in cleared reaches. Habitats with clay/silt and vegetation substrates were not found in the cleared reach, but were present in uncleared reaches. Mean S values based on depth and velocity were 14 out of a possible maximum of 25 for uncleared reaches but only 11 for cleared reaches. Habitat types corresponding to categories with velocities less than 1 $cm s^{-1}$ were generally present in uncleared reaches, but absent in cleared reaches.

DISCUSSION

Unfortunately, it was not possible for us to obtain reliable before and after data from the same reach. Our findings depend on comparison of adjacent cleared and uncleared reaches. Although these reaches were quite similar, uncontrolled variations doubtless were present. The simple procedures developed in this study for quantifying LWD density and its effect on channel resistance may be used for environmental impact assessment and planning-level hydraulic engineering analyses; however, considerable refinement and site-specific adaptation may be necessary. The method for prediction of channel roughness coefficients does not account for local losses due to bends or due to flow expansion and contraction at bridges, debris dams, or riffles. Our technique for determining roughness concentration yielded values that were reasonable in the light of published values for other streams that resulted from more labour-intensive measurement techniques. We did not collect detailed LWD density measurements that would have allowed us to assess the accuracy and precision of our technique.

Our results suggest that benefits of proposed LWD removal projects should be carefully analysed in the light of costs and environmental impacts. In channels similar to the one we studied, the flood control benefits of LWD removal may be modest. We found that removal of LWD from the study reaches decreased the Darcy–Weisbach friction factor for near-bankfull conditions by about one third and increased bankfull flow capacity by about one fourth. Furthermore, the difference in high-flow friction factors for the cleared and uncleared reaches may decline with time as LWD densities in cleared reaches recover. Inspection of the cleared study reaches following storms revealed additional LWD either from riparian trees falling into the channel or exposed in the bed as a result of scour. The LWD removal project in our study area was viewed by the constructing agency as a maintenance activity, and therefore was not subjected to benefit–cost analyses (personal communication, Mr Richard Swaim, Obion-Forked Deer Basin Authority, Jackson, Tennessee). Effects on channel hydraulics and habitats were not forecast.

Erosion triggered by LWD removal may increase channel maintenance costs. Although investigation of the LWD effects on channel stability was beyond the scope of this study, visual observation of bank erosion following LWD removal combined with evidence of headward-progressing degradation suggested that LWD removal may have triggered or exacerbated bed lowering through the upper portion of the study area. Similar observations of instability triggered by LWD removal have been reported by others (Bilby, 1984; Strom, 1950 cited in Gippel, 1989).

Our findings confirmed many of the intuitive suggestions by earlier workers (Marzolf, 1978; Yorke, 1978) regarding effects of LWD removal on habitats. Several impacts on physical aquatic habitat at base flow were measurable and statistically significant, even though the Stream Obstruction Removal Guidelines (IAFWA, 1983) were applied throughout project planning and implementation. Cleared reaches had greater depths, higher velocities, slightly coarser bed material, and were more uniform. Habitat surface area with velocity (at 0.6 depth) less than $30\,cm\,s^{-1}$ was reduced by about 50%, cover was reduced by 45 to 64%; and flow heterogeneity as measured by 90-percentile velocity was reduced at low flow but was unchanged for high flows. Relative to reported Shannon diversity values based on depth, velocity, and substrate for unaltered, smaller streams, which range between 2.8 and 4 (Gorman and Karr, 1978; Schlosser, 1987), even the uncleared reaches had low levels of physical diversity. Removal of LWD depressed Shannon indices by an additional 30 to 80%.

Mean LWD formation volume for cleared reaches was an average of almost 60% lower than for uncleared reaches. Habitat characteristics adjacent to remnant LWD formations and other types of cover in cleared reaches were similar to those adjacent to LWD and cover in uncleared reaches, although far less abundant. These areas tended to be shallower and have lower velocities and finer bed material with more organic matter than those distant from cover. Cover reduction may be the most important factor in regard to LWD removal impacts on fish populations (Hickman, 1975; Gore and Johnson, 1980; Hortle and Lake, 1983; Angermeier and Karr, 1984), while loss of LWD surfaces used as substrate is likely to be the most important factor for macroinvertebrates (Benke *et al.*, 1985), which has implications for higher trophic levels. Benke *et al.* (1985) reported that invertebrate assemblages on LWD are characterized by higher levels of species richness and diversity and by larger individuals than assemblages in adjacent sand beds. Although shifting sand may be densely inhabited by macroinvertebrates that have extremely high levels of biomass production, these animals are so small that their importance to higher trophic levels (i.e. fishes) is open to question. Preliminary analysis of benthic samples collected concurrently with our spring field study suggests that sediments under and immediately adjacent to LWD, which are finer, have higher levels of organic matter, and are sheltered from currents, tend to support larger organisms than adjacent sand beds (personal communications, B. Payne and A. Miller, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi).

Our findings were similar to those reported by Angermeier and Karr (1984) for effects of debris in small Illinois streams. They also observed that lower debris densities were associated with decreased occurrence of benthic organic litter and increased current velocity and proportion of sand bottom, but they found that debris removal decreased rather than increased depth. Results herein were also similar to those of Hauer (1989), who observed higher current velocities (20 to 30%) and lower levels of benthic organic matter (50 to 97%) in a South Carolina stream without significant LWD compared to a reference stream with LWD.

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REFERENCES

Alam, A. M. F. and Kennedy, J. F. 1969. 'Friction factors for flow in sand-bed channels', *Journal of the Hydraulics Division, American Society of Civil Engineers*, **95**, HY6, 1973–1992.

Anderson, N. H., Sedell, J. R., Roberts, L. M. and Triska, F. J. 1978 'The role of aquatic invertebrates in processing woody debris from coniferous forest streams', *American Midland Naturalist*, **100**, 64–82.

Angermeier, P. L. and Karr, J. R. 1984. 'Relationships between woody debris and fish habitat in a small warmwater stream', *Transactions of the American Fisheries Society*, **113**, 716–726.

Barnes, H. H. 1967. 'Roughness characteristics of natural channels', *Water Supply Paper 1849*, USDI Geological Survey, Washington DC.

Barstow, C. J. 1971. 'Impact of channelization on wetland habitat in the Obion-Forked Deer basin, Tennessee', in Trefethan, J. B. (Ed.) *Transactions of the 36th North American Wildlife Conference*, Wildlife Management Institute, Washington, DC. 362–376.

Benke, A. C., Henry, R. L., III, Gillespie, D. M. and Hunter, R. J. 1985. 'Importance of snag habitat for animal production in southeastern streams', *Fisheries*, **10**, 8–13.

Benke, A. C. and Parsons, K. A. 1990. 'Modelling black fly dynamics in blackwater streams'. *Freshwater Biology*, **20**, 167–180.

Beschta, R. L. and Platts, W. S. 1986. 'Morphological features of small streams: significance and function', *Water Resources Bulletin*, **22**, 369–379.

Beven, K., Gilman, K. and Newson, M. 1979. 'Flow and flow routing in upland channel networks', *Hydrologic Sciences Bulletin*, **24**, 303–325.

Bilby, R. E. 1980. 'Removal of woody debris may affect stream channel stability', *Journal of Forestry*, **82**, 609–613.

Bilby, R. E., and Likens, G. E. 1980. 'Importance of organic debris dams in the structure and function of stream ecosystems', *Ecology*, **61**, 1107–1113.

Cherry, J. and Beschta, R. L. 1989. 'Coarse woody debris and channel morphology: A flume study', *Water Resources Bulletin*, **25**, 1030–1036.

Chow, V. T. 1959. *Open-Channel Hydraulics*, McGraw-Hill, New York.

Coleman, R. L. and Dahm, C. N. 1990. 'Stream geomorphology: effects on periphyton standing crop and primary production', *Journal of the North American Benthological Society*, **9**, 293–302.

Fasken, G. B. 1963. *Guide for Selecting Roughness Coefficient 'n' Values for Channels*. USDA Soil Conservation Service, Lincoln, Nebraska.

Gippel, C. J. 1989. 'The hydraulic, hydrologic, and geomorphic significance of large woody debris (snags) in streams and rivers', *Proceedings, The State of Our Rivers Conference, 28–29 Sep 1989*, Centre for Continuing Education, the Australian National University, Canberra.

Gore, J. A. and Johnson, L. S. 1980. *Establishment of Biotic and Hydraulic Stability in a Reclaimed Coal Strip Mined River Channel'*, Institute of Energy and Environment, University of Wyoming, Laramie, Wyoming.

Gorman, O. T. and Karr, J. R. 1978. 'Habitat structure and stream fish communities', *Ecology*, **59**, 507–515.

Governor's West Tennessee Natural Resource Task Force. 1985. *Stream Renovation and Maintenance Guidelines for the Obion-Forked Deer River System*, Nashville, Tennessee.

Gregory, K. J., Gurnell, A. M. and Hill, C. T. 1985. 'The permanence of debris dams related to river channel processes,' *Hydrological Sciences Journal*, **30**, 371–381.

Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., Anderson, N. H., Cline, S. P., Aumen, N. G., Sedell, J. R., Lienkaemper, G. W., Cromak, K., Jr. and Cummins, K. W. 1986. 'Ecology of coarse woody debris in temperate ecosystems,' *Advances in Ecological Research*, **15**, 133–302.

Hauer, F. R. 1989. 'Organic matter transport and retention in a blackwater stream recovering from flow augmentation and thermal discharge,' *Regulated Rivers: Research and Management*, **4**, 371–380.

Hecht, B. and Woyshner, M. 1987. 'Effects of California riparian woodland on flood conveyance: Case of Pajaro River', *Proceedings, California Watershed Management Conference*, Report 11, Wildland Resources Center, University of California, Berkeley, California.

Hickman, G. D. 1975. 'Value of instream cover to the fish populations of Middle Fabius River, Missouri', *Aquatic Series, No. 14*, Missouri Department of Conservation, Jefferson City, Missouri.

Hortle, K. G. and Lake, P. S. 1982. 'Macroinvertebrate assemblages in channelized and unchannelized sections of the Bunyip River, Victoria', *Australian Journal of Marine and Freshwater Research*, **33**, 1071-1082.

Hortle, K. G. and Lake, P. S. 1983. 'Fish of channelized and unchannelized sections of the Bunyip River, Victoria', *Australian Journal of Marine and Freshwater Research*, **34**, 441–450.

Hubbard, E. F., Kilpatrick, F. A., Martens, L. A. and Wilson, J. F. 1982. 'Measurement of time of travel and dispersion in streams by dye tracing', Chapter A9 in *Techniques of Water Resources Investigations of the United States Geological Survey, Book 3, Applications of Hydraulics*, U. S. Geological Survey, Alexandria, Virginia.

Hupp, C. R. 1986. 'Vegetation and bank-slope development', *Proceedings of the Fourth Federal Interagency Sedimentation Conference, March 24–27, 1986*, Las Vegas, Nevada, Subcommittee on Sedimentation of the Interagency Advisory Committee on Water Data.

International Association of Fish and Wildlife Agencies (IAFWA). 1983. *Stream Obstruction Removal Guidelines*, Stream Renovation Guidelines Committee, Washington, DC.

Jarrett, R. D. 1984. 'Hydraulics of high-gradient streams', *Journal of Hydraulic Engineering*, **110**, 1519–1539.

Kouwen, N. and Unny, T. E. 1973. 'Flexible roughness in open channels', *Journal of the Hydraulics Division, American Society of Civil Engineers*, **99**, HY5, 713–728.

Li, R. and Shen, H. W. 1973. 'Effect of tall vegetation on flow and sediment', *Journal of the Hydraulics Division, American Society of Civil Engineers*, **99**, HY5, 793–814.

Little, A. D. 1973. *Report on Channel Modification*, Vols I and II, Council on Environmental Quality, Washington, DC.

Lovera, F. and Kennedy, J. F. 1969. 'Friction factors for flat-bed flows in sand-bed channels', *Journal of the Hydraulics Division, American Society of Civil Engineers*, **95**, HY4, 1227–1234.

Magurran, A. E. 1988. *Ecological Diversity and Its Measurement*, Princeton University Press, Princeton, New Jersey.

Marzolf, G. R. 1978. 'The potential effects of clearing and snagging on stream ecosystems', *Report No. FWS/OBS-78/14*, USDI Fish and Wildlife Service, National Stream Alteration Project, Columbia, Missouri.

Miller, B. A. and Wenzel, Harry G. 1985. 'Analysis and simulation of low flow hydraulics,' *Journal of Hydraulic Engineering*, **111**, 1429–1446.

Minckley, W. L. and Rinne, J. N. 1985. 'Large woody debris in hot-desert streams: an historical overview', *Desert Plants*, **7**, 142–153.

Parker, M. S. 1989. 'Effect of substrate composition on detritus accumulation and macroinvertebrate distribution in a southern Nevada desert stream', *The Southwestern Naturalist*, **34**, 181–187.

Petryk, S. and Bosmajian, G., III. 1975. 'Analysis of flow through vegetation', *Journal of the Hydraulics Division, American Society of Civil Engineers*, **101**, HY7, 871–884.

Prochzaka, K., Stewart, B. A. and Davies, B. R. 1991. 'Leaf litter retention and its implications for shredder distribution in two headwater streams', *Archiv für Hydrobiologie*, **120**, 315–325.

Robison, E. G. and Beschta, R. L. 1990. 'Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA', *Canadian Journal of Fisheries and Aquatic Sciences*, **47**, 1684–1693.

Schlosser, I. J. 1987. 'A conceptual framework for fish communities in small warmwater streams', in Matthews, W. J. and Heins, D. C. (Eds) *Community and Evolutionary Ecology of North American Stream Fishes*, University of Oklahoma Press, Norman, Oklahoma, 17–24.

Shields, F. D., Jr. and Milhous, R. T. 1992. 'Sediment and aquatic habitat in river systems', *Journal of Hydraulic Engineering*, **118**, 669–687.

Shields, F. D., Jr. and Nunnally, N. R. 1984. 'Environmental aspects of clearing and snagging', *Journal of Environmental Engineering*, **110**, 152–165.

Shields, F. D., Jr. and Hoover, J. J. 1991. 'Effects of channel restabilization on habitat diversity, Twentymile Creek, Mississippi,' *Regulated Rivers: Research and Management*, **6**, 163–182.

Simon, A. 1989. 'The discharge of sediment in channelized alluvial streams', *Water Resources Bulletin*, **25**, 1177–1188.

Simon, A. and Hupp, C. R. 1986. 'Channel evolution in modified Tennessee channels', *Proceedings, Fourth Interagency Sedimentation Conference, 24–27 March 1986, Las Vegas, NV*, 5-71–5-82.

Simon, A. and Hupp, C. R. 1987. 'Geomorphic and vegetative recovery processes along modified Tennessee streams: an interdisciplinary approach to distributed fluvial systems', *Forest Hydrology and Watershed Management*, Proceedings of the Vancouver Symposium, IAHS-AISH Publication No. 167, Institute of Hydrology, Wallingford. 251–262.

Smith, G. F. and Badenhop, M. B. 1975. 'An evaluation of environmental quality: opportunity costs of channelization and land use change in the floodplain of the Obion-Forked Deer River Basin of West Tennessee', *Bulletin 552*, The University of Tennessee, Agricultural Experiment Station, Knoxville, Tennessee.

Smith, R. H., Shields, F. D., Jr. Dardeau, E. A., Jr., Schaefer, T. E., Jr. and Gibson, A. C. In press. 'Incremental effects of large woody debris removal on physical aquatic habitat', Technical report, environmental impact research program, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Strom, H. G. 1950 'River improvements—methods used in Victoria', *Aqua* Sept, 18–23

US Engineer Office, Mobile, Alabama. 1940. *The Effect of Channel Improvement for Flood Control, East Fork of the Tombigbee River Mississippi*, Mobile, Alabama.

Wallace, J. B. and Benke, A. C. 1984. 'Quantification of wood habitat in subtropical coastal plain streams', *Canadian Journal of Fisheries and Aquatic Sciences*, **41**, 1643–1652.

Yorke, T. H. 1978. 'Impact assessment of water resource development activities', *Report FWS/OBS-78/82*, USDI Fish and Wildlife Service, Office of Biological Services, Washington, DC.

Young, W. J. 1991. 'Flume study of the hydraulic effects of large woody debris in lowland rivers,' *Regulated Rivers: Research and Management*, **6**, 203–211.

Zimmer, D. W. and Bachman, R. W. 1976. 'A study of the effects of stream channelization and bank stabilization on warmwater sport fish in Iowa; subproject No. 4. The effects of long-reach channelization on habitat and invertebrate drift in some Iowa streams', *Report No. FWS/OBS-76/14*, USDI Fish and Wildlife Service, Washington, DC.

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Surveys of basking map turtles *Graptemys* spp. in three river drainages and the importance of deadwood abundance

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Abstract

Eight replicated spotting-scope surveys of basking turtles and deadwood were conducted in the Pearl and Pascagoula river drainages in Mississippi and Louisiana and the lower Tennessee River in Kentucky. Basking densities of two "narrow-headed" *Graptemys*, listed as Threatened under the US Endangered Species Act and as Endangered by the International Union for the Conservation of Nature, were 2.3 per 100 m of riverbank for *G. oculifera* in the Pearl drainage, and 0.8 per 100 m for *G. flavimaculata* in the Pascagoula drainage. Density of *G. flavimaculata* met threshold values established for delisting at three of 16 sites. Density of the unlisted narrow-headed *G. ouachitensis* in the Tennessee drainage was 2.9 turtles per 100 m of shoreline. Density of an unlisted "broad-headed" species, *G. gibbonsi*, was 5.1 times lower than density of the two sympatric listed species in the Pearl and Pascagoula drainages and the broad-headed species *G. pseudogeographica kohnii* from the Tennessee drainage. *Graptemys gibbonsi* was only recently described and should be considered for listing. Correlations of *Graptemys* or total turtle density with deadwood density were positive in all cases and significant in five of nine analyses, and high basking densities were never associated with low deadwood densities. Removal of deadwood from rivers is thus probably detrimental to *Graptemys* populations.

Keywords: Map turtles; *Graptemys flavimaculata*; *Graptemys gibbonsi*; *Graptemys oculifera*; *Graptemys ouachitensis*; *Graptemys pseudogeographica kohnii*; Deadwood; Abundance; Species status

1. Introduction

Anthropogenic impacts on large rivers in the United States include impoundment, channelization, water-quality degradation, and introduction of exotic predators and competitors (Lydeard and Mayden, 1995). Rivers of the southeastern United States are of special conservation concern because they are exceptionally diverse freshwater communities, particularly with regard to gill-breathing snails, mussels, fishes, and turtles (Lydeard and Mayden, 1995).

Map turtles *Graptemys* are a speciose genus of primarily riverine emydid turtles, with 12 species recognized (Ernst et al., 1994). The genus is characterized by a high degree of river-drainage endemism. Three species have wide ranges primarily within the Mississippi River drainage, while eight of the other nine are restricted to single smaller Gulf Coast drainages, and one occurs in two small adjacent Gulf Coast drainages (Lamb et al., 1994).

The ringed map (= sawback) turtle *G. oculifera* of the Pearl River drainage in Mississippi and Louisiana and the yellow-blotched map (= sawback) turtle *G. flavimaculata* of the Pascagoula River drainage in Mississippi are listed as Threatened under the US Endangered Species Act (ESA) of 1973 as amended (US Fish and Wildlife Service, 1988, 1993). *Graptemys caglei* is a current candidate for listing under the ESA and four other *Graptemys* have been candidates in the recent past. The International Union for the Conservation of Nature (IUCN) lists *G. oculifera* and *G. flavimaculata* as Endangered, *G. caglei* as Vulnerable, and five other *Graptemys* species as Lower Risk/near threatened. The US Fish and Wildlife Service noted several threats to survival of *G. oculifera* and *G. flavimaculata* (Stewart, 1986, 1991): (1) habitat modification on the Pearl and Pascagoula drainages, including "snagging" (the

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removal of deadwood from the river channel), channelization, and impoundment; (2) several planned engineering projects which would further threaten to alter the two drainages; (3) colorful markings, unusual shell morphology, and general rarity which make both species highly desirable to collectors; (4) shooting of basking turtles; and (5) municipal and industrial effluents.

Accumulated deadwood in river channels is important to map turtle ecology in at least three distinct ways. Map turtles are among the most habitual of basking turtles (Boyer, 1965; Waters, 1974; Pluto and Bellis, 1986; Lindeman, 1993, 1997a). Basking serves multiple functions, including thermoregulation and ridding turtles of shell and skin parasites (Boyer, 1965; Moll and Legler, 1971; Vogt, 1979).

Deadwood also serves as a substrate for prey organisms of "narrow-headed" *Graptemys*, including *G. oculifera* and *G. flavimaculata* (Waters, 1974; Moll, 1976 and pers. comm.; Shively and Jackson, 1985; Kofron, 1991; Seigel and Brauman, 1994; Lindeman, 1997a). Deadwood may also serve as a grazing substrate for juveniles and males of "broad-headed" *Graptemys*, in which the sexual size dimorphism (females larger) typical of *Graptemys* is most extreme (Gibbons and Lovich, 1990). Females of these species have wider heads than males (even with correction for body-size differences; Lindeman, 1997a) as an adaptation for molluscivory, but males feed on prey similar to the prey of narrow-headed species (Sanderson, 1974; Vogt, 1981; Lindeman, 1997a). Finally, deadwood is used by map turtles as a substrate while resting or sleeping (Chaney and Smith, 1950).

The present study had two major objectives: (1) to determine the basking densities of *G. oculifera* and *G. flavimaculata* in the Pearl and Pascagoula drainages and compare these data with data for the sympatric, broad-headed species *G. gibbonsi*, the allopatric, narrow-headed species *G. ouachitensis*, and the allopatric, broad-headed species *G. p. kohnii*; and (2) to determine the relationship between map turtle abundance and deadwood abundance.

2. Materials and methods

2.1. Data collection

Replicated spotting-scope counts were conducted at fixed locations on the Pearl ($n=20$ sites) and Pascagoula ($n=21$) River drainages in Mississippi and Louisiana, and on Kentucky Lake and the Tennessee River below Kentucky Lake Dam ($n=20$) in western Kentucky (Table 1; maps in Lindeman, 1996, 1997b). The Pearl and Pascagoula rivers are wide rivers with moderate current and are dominated by sandy, forested riverbanks that are little developed. Sites on Kentucky Lake are part of the Tennessee Valley Authority's Land Between the Lakes Recreation Area, a forested uninhabited area with minimal shoreline development and numerous side embayments representing old creek beds.

Most sites were visited four times in 1994 and four times in 1995; seven sites could not be visited all eight times due to flooding or changes in public access. Surveys were restricted to May and June and 09.00–15.00, and were conducted on sunny warm (>20°C) days, to insure relatively high and uniform basking densities (Boyer, 1965; Waters, 1974; Lindeman, 1997a). Basking frequency is variable and dependent upon several biotic and abiotic factors (Boyer, 1965; Hammond et al., 1988), thus counts were replicated to account for natural variability in the number of turtles basking.

From one to three fixed locations on shore, I counted all basking turtles I could see with a spotting scope with 22–60× zoom magnification. Turtles were identified to species, although some could only be recorded as *Graptemys* sp., *Apalone* sp., or unidentified emydids. Each turtle was recorded by bank on which it occurred and type of substrate it occupied. Whether or not turtles occupied the same substrate was also noted. Length of riverbank or shoreline scanned during each count was estimated visually to the nearest 25 m (maximum range 125 m from a fixed location).

Emergent deadwood was also counted during each survey. Categorization of deadwood was necessary to account for the fact that deadwood substrates may differ in value to *Graptemys* due to differences in total surface area of submerged and emergent portions. Substrates were classified as: (1) logs as wide or wider than the carapace width of large emydids (≥c. 20 cm) angled at <45°; (2) branches, single basking substrates <c. 20 cm wide, or wider but angled at >45°; (3) tangles, including emergent root masses of submerged fallen trees, and clusters of woody debris washed together; (4) stumps; or (5) crowns, consisting of several emergent branches and often the emergent trunks of single fallen trees.

2.2. Data analysis

For each drainage I developed an index of deadwood density (IDD) by calculating, over all counts at all sites on the drainage, both the proportion of each type of substrate occupied by one or more turtles (O_i, where i is the substrate type), and the mean number of turtles (of all species) per occupied substrate (M_i). Both figures were multiplied by the number of each type of substrate (N_{ij}) observed at a site j on the drainage. Products were summed, and the sum converted to deadwood density at the site by dividing by the number of 100-m sections of riverbank or shoreline (D_j) observed (summed over all surveys) at the site, hence:

Table 1
Location of sites on three river drainages

Drainage	Portion of drainage	Sites
Pearl	Pearl River	ABC EF J LM PQR
	Yockanookany River	D
	Ross Barnett Reservoir	GHI
	Mayes Lake	K
	Strong River	NO
	Bogue Chitto River	S
	West Pearl River	T
Pascagoula	Leaf River	AB E GH
	Bowie River	CD
	Tallahala Creek	F
	Chunky River	I
	Chickasawhay River	JKLMNOPQ
	Pascagoula River	RS U
	Black Creek	T
Tennessee	Lower Tennessee River	ABCDE
	Kentucky Lake	FGHIJKLMNOPQRST

Lettering is from north to south on each tributary. Maps of these sites appear in Lindeman (1996, 1997b).

$$IDD_j = [\Sigma(O_i N_{ij}) + \Sigma(M_i N_{ij})]/D_j.$$

The relationship of basking density to (1) IDD and (2) total number of deadwood substrates was examined with Pearson correlation coefficients and simple linear regression analyses. Basking densities were calculated for individual *Graptemys* species in each drainage, total *Graptemys* (including those not identified to species), total emydids, and total turtles. I conducted these analyses separately for each drainage, using: (1) each site as an independent data point, with densities of turtles and deadwood expressed as averages over all surveys weighted by amount of shoreline or riverbank surveyed during each count; and (2) data sets limited to observations of the maximum observed densities (all turtle species) for each site. If overall turtle abundance is not related to deadwood abundance, then I would expect no correlation between basking density and deadwood density, because turtles in a site with little deadwood could, assuming an equal basking tendency, crowd onto the few substrates available and thus still be counted in my surveys. *Graptemys* crowd together in large numbers on single basking substrates, with little aggression (Boyer, 1965; Vogt, 1980b; Lindeman, 1997a).

Because the above analyses are for sites spread over the entire geographic ranges of *G. oculifera*, *G. flavimaculata*, and *G. gibbonsi*, the relationship between basking incidence and deadwood abundance may be partially obscured by other factors which determine turtle abundance, such as river width and depth, water temperature, current speed, sunlight, prey base, degree of anthropogenic disturbance, etc. (Shively and Jackson, 1985; Fuselier and Edds, 1994; Jones, 1996). I therefore tested for local differences in density of species of *Graptemys* or total turtle density as related to IDD by comparing data from (1) five pairs of sites that were closely situated, and (2) five sites at which I was able to see > 100 m of both river banks from my point(s) of observation. For both types of sites I conducted analyses of variance (ANOVA) for differences in turtle density and IDD. I restricted analyses of pairs of sites to those providing similar habitat.

3. Results

3.1. Data collected during replicated surveys

I observed an average of 3.32 turtles/100 m in the Pearl drainage, 1.53 turtles/100 m in the Pascagoula drainage, and 9.17 turtles/100 m in the Tennessee drainage (Table 2). *Graptemys* species were among the predominant species observed in each drainage. For each of the five types of basking substrate, the proportion occupied (O_i) and the mean number of turtles (M_i) were highest for the Tennessee drainage and lowest for the Pascagoula drainage (Table 3). Relative differences in O_i and M_i were similar across the three drainages in spite of the differences in turtle density.

Densities of potential basking substrates were not significantly different among drainages except in the case of stumps, of which the Pearl drainage had a significantly higher density than the Tennessee drainage (Table 4). Basking densities of narrow-headed *Graptemys* (*G. oculifera*, *G. flavimaculata*, and *G. ouachitensis*), although two to three times lower in the Pascagoula drainage than in the other two drainages, were not significantly different (Table 4) due to the variation in densities observed among sites within each drainage (Fig. 1). Density of the broad-headed

Table 2
Results of replicated counts of basking turtles in three drainages, including total length of riverbank or shoreline summed over all counts, total turtles observed, turtles per 100 m, and predominant species

Drainage	Length (m)	Total turtles observed	Turtles per 100 m	Predominant species (%)
Pearl	42 275	1405	3.32	*Graptemys oculifera* (75.2) *Pseudemys concinna* (8.2) *G. gibbonsi* (7.8)
Pascagoula	42 225	644	1.53	*G. flavimaculata* (53.2) *G. gibbonsi* (21.9) *P. concinna* (20.1)
Tennessee	20 175	1851	9.17	*Trachemys scripta* (48.7) *G. ouachitensis* (29.2) *G. pseudogeographica kohnii* (16.7)

Table 3
Occurrence of deadwood and occupancy by basking turtles, for three river drainages

Drainage	Substrate	Total	Number occupied (%)		Total turtles	Mean per occupied substrate
Pearl	Log	1336	228	(17)	492	2.16
Pascagoula	Log	1524	178	(12)	278	1.56
Tennessee	Log	716	266	(37)	959	3.61
Pearl	Branch	3773	486	(13)	773	1.59
Pascagoula	Branch	4850	221	(5)	256	1.16
Tennessee	Branch	2021	363	(18)	601	1.66
Pearl	Tangle	250	18	(7)	41	2.28
Pascagoula	Tangle	286	11	(4)	14	1.27
Tennessee	Tangle	74	19	(26)	55	2.89
Pearl	Stump	437	16	(4)	18	1.13
Pascagoula	Stump	249	4	(2)	4	1.00
Tennessee	Stump	57	9	(16)	14	1.56
Pearl	Crown	42	19	(45)	66	3.47
Pascagoula	Crown	48	7	(15)	12	1.71
Tennessee	Crown	24	23	(96)	155	6.74

Table 4
Average density (per survey site) of deadwood and turtles for three river drainages over eight replicated surveys

Substrate type/taxon	Mean density per 100 m within drainage			ANOVA results
	Tennessee	Pascagoula	Pearl	
Logs	3.6	3.9	3.2	NS
Branches	10.6	12.3	9.0	NS
Tangles	0.4	0.8	0.6	NS
Stumps	0.2a	0.6a,b	1.1b	[b]
Tree crowns	0.1	0.1	0.1	NS
Total substrates	15.0	17.8	14.0	NS
Narrow-headed *Graptemys*	2.9	0.8	2.3	NS
Broad-headed *Graptemys*	1.3	0.3a	0.2a	[b]
Total *Graptemys*	4.6a	1.2b	2.6a,b	[a]
Total emydids	9.5	1.5a	3.0a	[c]
Total turtles	9.6	1.6a	3.2a	[c]

For variables with significant differences among drainages (ANOVA, $p < 0.05$), densities with the same on-line letter were not significantly different in Fisher's LSD tests ($p > 0.05$).

[a] $p < 0.05$.
[b] $p < 0.01$.
[c] $p < 0.001$.

G. p. kohnii in the Tennessee drainage was significantly higher than for the broad-headed *G. gibbonsi* in either the Pearl or Pascagoula drainage. Total *Graptemys* density and total turtle density were significantly higher in the Tennessee drainage than in the Pascagoula drainage, and total emydid basking density was higher in the Tennessee drainage than in either southern drainage.

3.2. Correlation of turtle density with deadwood density

In analyses using weighted averages or maximum basking densities per site, there were significant correlations between deadwood abundance and basking densities of *G. ouachitensis* in the Tennessee drainage, *G. gibbonsi* in the Pearl drainage, *G. flavimaculata* in the Pascagoula drainage, and *G. oculifera* in the Pearl drainage, but not for *G. p. kohnii* in the Tennessee drainage or *G. gibbonsi* in the Pascagoula drainage (Table 5). Correlations between deadwood density and basking densities were significant in all 12 analyses for total *Graptemys*, total emydids, and total turtles in the Tennessee drainage, and for 13 of 24 analyses in the Pearl and Pascagoula drainages (Table 5). Correlation coefficients were generally similar regardless of whether IDD or total number of potential substrates was used as the independent variable; in 19 of 24 pairs of analyses, the decision to reject or not reject the null hypothesis was the same regardless of which was used (Table 5). Regressions of weighted-average densities of each species of *Graptemys* and of total turtles on IDD appear in Fig. 1.

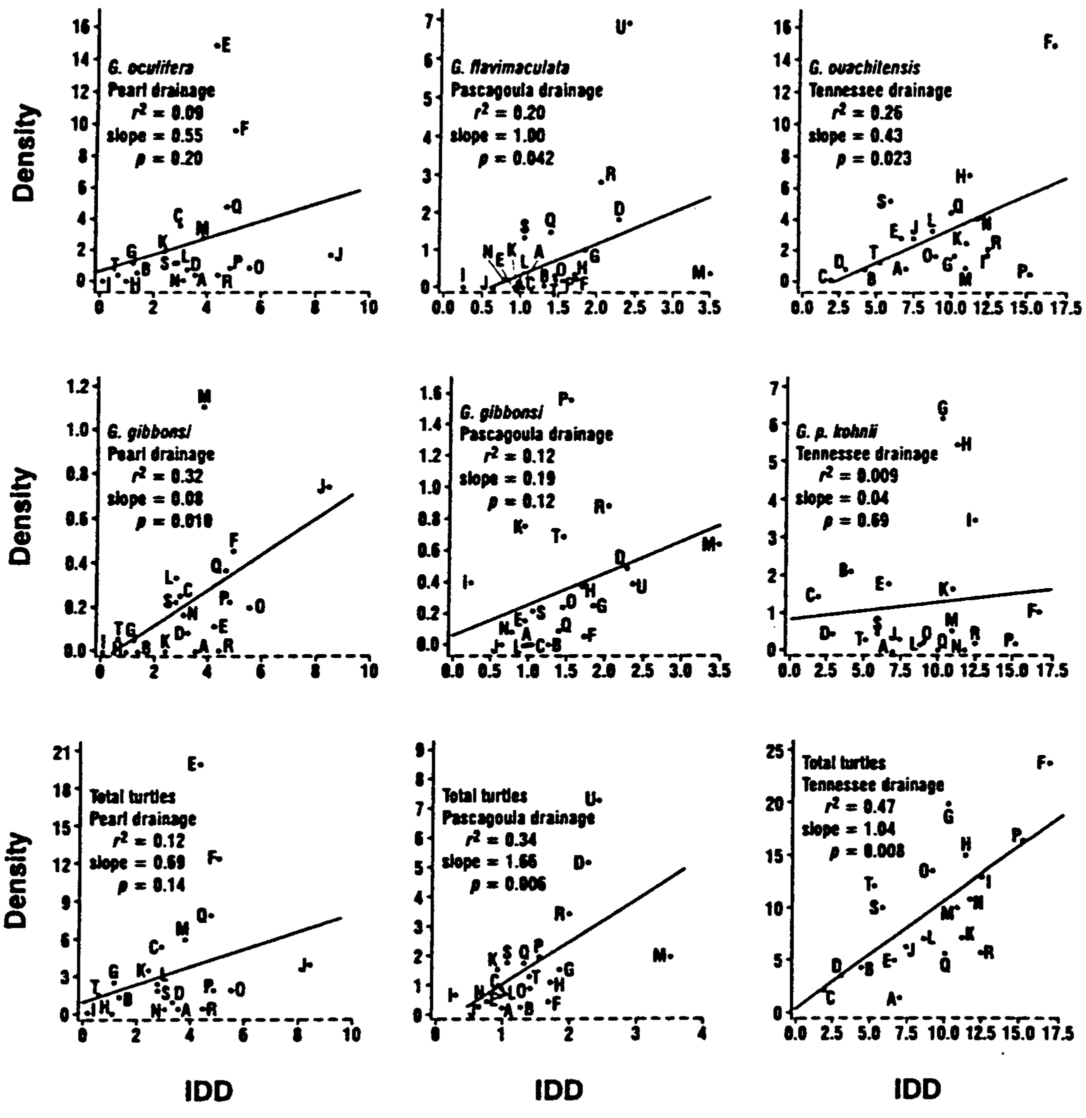

Fig. 1. Regressions of weighted-average densities on an index of deadwood density (IDD), for five species of *Graptemys* and total turtles in three river drainages. IDD is based on drainage-wide proportional use of five basking-substrate categories for basking by turtles of all species and the densities of substrates of those categories at individual sites (see text). Letters correspond to survey sites in Table 1. The first row contains data on narrow-headed species of *Graptemys* for each drainage, the second contains data on broad-headed species of *Graptemys*, and the third contains data on turtles of all species.

Table 5
Pearson correlation coefficients relating deadwood density to densities of various taxa of turtles in three river drainages

Drainage	Data set	*Graptemys flavimaculata*	*Graptemys oculifera*	*Graptemys ouachitensis*	*Graptemys gibbonsi*	*Graptemys p. kohnii*	Total *Graptemys*	Total emydids	Total turtles
Pearl	IDD/WA		0.30		0.56^{b}		0.33	0.31	0.34
	TPS/WA		0.35		0.53^{a}		0.38	0.36	0.38
	IDD/MD		0.28		0.44		0.32	0.29	0.30
	TPS/MD		0.45^{a}		0.28		0.48^{a}	0.45^{a}	0.48^{a}
Pascagoula	IDD/WA	0.45^{a}			0.35		0.50^{a}	0.56^{b}	0.58^{b}
	TPS/WA	0.46^{a}			0.34		0.52^{a}	0.54^{a}	0.56^{b}
	IDD/MD	0.41			0.05		0.42	0.55^{a}	0.58^{b}
	TPS/MD	0.31			−0.03		0.28	0.39	0.44^{a}
Tennessee	IDD/WA			0.51^{a}		0.10	0.47^{a}	0.71^{b}	0.69^{b}
	TPS/WA			0.67^{b}		0.04	0.59^{b}	0.73^{b}	0.71^{b}
	IDD/MD			0.47^{a}		−0.02	0.45^{a}	0.69^{b}	0.67^{b}
	TPS/MD			0.50^{a}		−0.11	0.46^{a}	0.71^{b}	0.70^{b}

Data used for analyses varied according to whether deadwood abundance was expressed as an index of deadwood abundance (IDD; see text), or as total potential substrates (TPS), and by whether data on turtle and deadwood abundance were expressed by computing weighted averages (WA) at each site, or limiting analysis to counts with maximum densities (MD) at each site.
[a] $p<0.05$.
[b] $p<0.01$.

3.3. *Analyses of adjacent and single sites*

At adjacent sites on the Pearl and Pascagoula drainages, the general trend was that significant differences in IDD were associated with significant differences in basking densities, while nonsignificant differences in IDD were associated with nonsignificant differences in basking densities (Table 6). Similar results were obtained for analysis of opposite riverbanks of three of five single sites (Table 7).

4. Discussion

4.1. *Comparison of drainages*

The three river drainages studied were similar in deadwood density, but differed significantly in total density of basking turtles, with the Tennessee drainage having 3 times the density of turtles of the Pearl drainage and 6 times the density of the Pascagoula drainage (Table 4). Basking densities of total *Graptemys* and of the three narrow-headed species of *Graptemys* also followed the pattern of being highest in the Tennessee drainage and lowest in the Pascagoula drainage. The two *Graptemys* listed as Threatened under the US ESA were the predominant species observed in their respective drainages, whereas *G. ouachitensis* was the second most frequently observed species in the Tennessee drainage.

4.2. *Conservation status of the three southern* Graptemys

4.2.1. Graptemys oculifera

Basking densities of *G. oculifera* in the Pearl drainage approached those of an unlisted and ecologically similar species, *G. ouachitensis*, in the Tennessee drainage

Table 6
Results of ANOVA analyses comparing the index of deadwood density (IDD) and basking densities of turtles at adjacent sites over eight surveys on two drainages

Drainage	Sites	IDD	*Graptemys oculifera*	*Graptemys flavimaculata*	*Graptemys gibbonsi*	Total turtles
Pearl	E, F	NS	NS	–	NS	NS
Pearl	L, M	NS	M^{a}	–	M^{b}	M^{b}
Pascagoula	D, E	D^{c}	–	D^{b}	NS	D^{b}
Pascagoula	G, H	NS	–	NS	NS	NS
Pascagoula	L, M	M^{c}	–	NS	M^{b}	M^{a}

The site with the higher value is indicated for significant differences.
[a] $p<0.05$.
[b] $p<0.01$.
[c] $p<0.001$.

Table 7
Results of ANOVA analyses comparing the index of deadwood density (IDD) and basking densities of turtles for right (R) and left (L) riverbanks at single sites over eight surveys on two drainages

Drainage	Site	IDD	*Graptemys oculifera*	*Graptemys flavimaculata*	*Graptemys gibbonsi*	Total turtles
Pearl	C	NS	R[b]	–	NS	R[c]
Pearl	E	NS	NS	–	NS	NS
Pearl	M	R[c]	R[b]	–	R[a]	R[c]
Pascagoula	K	NS	–	–	NS	NS
Pascagoula	R	[c] (R > C,L)	–	NS	NS	NS

The side with the higher value is indicated for each significant difference. For Site R on the Pascagoula drainage, deadwood stranded against center (C) bridge abutments created a third category, and significant differences were determined using Fisher's LSD tests.
[a] $p<0.05$.
[b] $p<0.01$.
[c] $p<0.001$.

(Fig. 1). Basking density of *G. oculifera* was highest just below the Ringed Sawback Turtle Refuge (Sites E and F), and was notably low in the Ross Barnett Reservoir (Sites G, H, and I), where much of the shoreline is developed, with few shoreline trees to provide sources of deadwood (Fig. 1). This contrasts with Kentucky Lake, which had lower basking and deadwood densities at sites on the Tennessee River relative to sites on Kentucky Lake (Fig. 1). Higher deadwood densities on Kentucky Lake are undoubtedly attributable to the lack of shoreline development, and lower densities below the dam on the Tennessee River may be related to rapid changes in flow from the dam outlet.

The US Fish and Wildlife Service's (1988) recovery plan for *G. oculifera* states that recovery will be achieved (1) once a minimum of 242 km of river habitat is protected, with (2) at least 48 km both above and below Ross Barnett Reservoir, and (3) once populations have been observed to be stable or increasing for at least 10 years. Data from the present study supplement data from Jones and Hartfield (1995), providing a baseline for future investigations of population status and recovery. Recent mark-recapture studies of the same five short (3.2–4.8 km) river segments studied earlier by Jones and Hartfield (1995) indicate a decline in numbers at four of the five since 1990 (R. Jones, pers. comm.). Four of Jones and Hartfield's survey sites were immediately upstream of sites I surveyed (R. Jones pers. comm.).

For *G. oculifera* in the present study, Sites C, E, and Q had about 6, 3, and 10 times higher mean basking densities than the upstream river segments they surveyed, while Site P had about four-fifths the basking density of their upstream segment. These generally higher numbers should be regarded with caution due to differences in sampling methods and localities.

4.2.2. Graptemys flavimaculata

Although it was the dominant species in basking surveys on the Pascagoula drainage, *G. flavimaculata* was relatively uncommon compared to its two narrow-headed congeners in the Pearl and Tennessee drainages. Basking density was especially low on the Leaf and Chickasawhay Rivers, where the species may have undergone a range reduction. Site A on the Leaf River and Sites J and K on the Chickasawhay Rivers are the furthest upstream points at which *G. flavimaculata* has been observed or collected in past studies (Cliburn, 1971; McCoy and Vogt, 1979). No *G. flavimaculata* were seen at these sites during replicated surveys in 1994 and 1995, and densities were low at locations downstream from these sites (Sites B, E, and L–O; Fig. 1). Densities of all turtles tended to also be low at these locations (Fig. 1).

According to the recovery plan for *G. flavimaculata*, delisting is conditioned upon consistent observation of basking densities of 44 individuals/km in the Pascagoula River and 22 individuals/km in both the Leaf and Chickasawhay Rivers, plus watershed protection of the entire Pascagoula River and 129 km in each of the Leaf and Chickasawhay Rivers (US Fish and Wildlife Service, 1993). Because density figures would include turtles on both banks, densities in Fig. 1 must be doubled, and multiplied by 10 to convert to turtles/km. With this correction, observed weighted-average basking densities ranged from 28 to 138 (mean 74) *G. flavimaculata*/km at three sites on the Pascagoula River, from 0 to 29 (mean 6) individuals/km at eight sites on the Chickasawhay River, and from 0 to 20 (mean 6) individuals/km at five sites on the Leaf River. Current populations of *G. flavimaculata* meet the thresholds designated for recovery (and subsequent delisting) at only three of 16 sites (Q, S, and U) examined.

4.2.3. Graptemys gibbonsi

The conservation status of *G. gibbonsi* needs attention, given that (1) its geographic range coincides with the composite range of the two *Graptemys* listed under the US ESA and by the IUCN (Lamb et al., 1994) and (2) the two listed species outnumbered it in total

basking counts by 5.1:1. Trapping studies on the Pearl River suggest *G. gibbonsi* was about twice as abundant as *G. oculifera* in the 1950s and 1960s (Cagle, 1953; Tinkle, 1958; Cliburn, 1971) and slightly less common than *G. oculifera* in the late 1970s (Vogt, 1980a). Trapping in 1988–1990 (Jones and Hartfield, 1995; R. Jones, pers. comm.) yielded ratios of *G. oculifera*: *G. gibbonsi* of 3.3:1, 46:1, 4.5:1, and 1.9:1 upstream from my Sites C, E, P, and Q, respectively, compared to 15:1, 125:1, 3.5:1, and 13:1 in the present study. A similar marked decline in *G. gibbonsi* relative to *G. flavimaculata* on the Pascagoula drainage is evident based on a comparison of trapping data from the 1950s and 1960s (Tinkle, 1958; Cliburn, 1971) with data from the present study.

Water-quality degradation may negatively affect the molluscan prey of *G. gibbonsi*. This species was described as separate from *G. pulchra* of the Mobile Bay drainage only after its two sympatric congeners had been listed (Lovich and McCoy, 1992). I suggest that *G. gibbonsi* is a candidate for listing under the US ESA as Threatened, and by the IUCN as Endangered, and that it should be so listed unless it can be shown that either (1) the species has a much lower basking frequency than its two sympatric congeners, and thus was less likely to be observed in my basking surveys [or captured in basking traps by Jones and Hartfield (1995)], or (2) larger upstream populations exist, beyond the range of the two narrow-headed species. Such a phenomenon was described for sympatric narrow- and broad-headed *Graptemys* in Louisiana (Shively and Jackson, 1985). Upstream sites, particularly in smaller tributaries, may be protected from some of the factors that impact the species.

4.3. Importance of deadwood abundance

Not all correlations of basking densities of individual *Graptemys* species or total turtles with deadwood density were significant (Table 5). However, even non-significant correlations showed a pattern: moderate-to-high basking densities were always associated with moderate-to-high densities of deadwood (Fig. 1). This relationship suggests that while deadwood is necessary for large populations of *Graptemys*, it is not sufficient; some sites with good deadwood abundance lacked other important habitat characteristics, perhaps relating to current speed or channel morphology. The positive relationship between density of basking turtles and density of deadwood cannot be attributed to a simple increase in basking opportunity (independent of total turtle density) as basking substrates become more numerous. Most deadwood was not occupied by turtles (Table 3), and occupied deadwood usually had room for more turtles than were present. Analysis of pairs of closely-situated sites and the two riverbanks of single sites on the Pearl and Pascagoula drainages tended to corroborate the positive relationship between basking density and deadwood density.

Abundance of basking substrates was an important habitat variable determining *Graptemys* abundance in Kansas (Fuselier and Edds, 1994) and Pennsylvania (Pluto and Bellis, 1986), and radiotelemetry work with *G. flavimaculata* on the lower Pascagoula River also demonstrated the importance of deadwood to habitat selection (Jones, 1996). The abundance of basking substrates may also be important for other riverine turtles (e.g. Kramer, 1995), and Mills et al. (1995) established a positive correlation between deadwood abundance and the abundance of a basking aquatic snake. Mills et al. (1995) and Jones (1996) found especially high densities of deadwood and study animals on the outer bends of rivers, similar to my findings for a 180° turn in the Pearl River at Site M. The outer bend had more than three times the average IDD and average total turtle density as the inner bend. In addition to the high deadwood densities on outer bends of rivers, inner-bend sandbars used for nesting may attract adult females to these segments of river during the nesting season (R. Brauman, pers. comm.).

4.4. Implications for river management

The present study demonstrates that basking densities of turtles are lower in areas characterized by low densities of deadwood (Fig. 1). If one assumes an equal basking tendency, then total *Graptemys* density is low at sites with low deadwood abundance. Thus removal of deadwood, as has been traditionally practiced, should be expected to have a detrimental effect on *Graptemys* populations, through the loss of basking, food, and resting substrates. In the Ringed Sawback Turtle Refuge on the Pearl River, which has heavy recreational boat traffic, current practice is to move deadwood from the middle of the river channel to within a few meters of the nearest bank, rather than to remove it from the river altogether (R. Jones, pers. comm.). This change in traditional snagging operations should benefit *G. oculifera* and other freshwater turtles that depend on deadwood. The only possible detrimental effect of this practice would be the loss of deep-water substrates further from the riverbank, which may be used relatively more often as basking substrates (Flaherty and Bider, 1984). Deadwood often collects around bridge supports (pers. obs.) and data from Site R on the Pascagoula River demonstrate use of such substrates for basking (Table 7). Snagging operators may consider anchoring deadwood upstream and downstream of bridge supports to provide deepwater, fast-current substrates that would not impede boat traffic.

The low densities of *G. flavimaculata* in the Pascagoula drainage, particularly in the upper Leaf and upper Chickasawhay Rivers, strongly suggest that problems

other than loss of deadwood may be a major factor in this species' decline. Water-quality degradation has been especially acute in the Leaf drainage (US Fish and Wildlife Service, 1993), and recreational fishing on the Leaf River has suffered following a pulp mill discharge in 1992 (R. Jones, pers. comm.). The possibility of toxic effluents on the upper portions of these drainages becoming more diluted further downstream would explain the higher densities of *G. flavimaculata* and other turtles further downstream and in the Pascagoula River, and toxicity in the upper Leaf would help to explain the dramatic difference between Site D on the mouth of the Bowie River (second highest total turtle basking density for the drainage; Fig. 1) and Sites A, B, and E on the Leaf River. The low numbers of turtles seen at Site E may also be related to intensive instream gravel mining that has occurred there (R. Jones, pers. comm.). Site C, further upstream on the Bowie River and with only *Pseudemys concinna* observed, is a popular swimming hole for local residents. Protection of the Bowie River drainage would thus not only protect the most important upstream refuge for turtle populations including *G. flavimaculata* in the Pascagoula drainage (Fig. 1), but would also protect recreational interests.

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References

Boyer, D.R., 1965. Ecology of the basking habit in turtles. Ecology 46, 99–118.

Cagle, F.R., 1953. The status of the turtle *Graptemys oculifera* (Baur). Zoologica 38, 137–144.

Chaney, A., Smith, C.L., 1950. Methods for collecting mapturtles. Copeia 1950, 323–333.

Cliburn, J.W., 1971. The ranges of four species of *Graptemys* in Mississippi. Journal of the Mississippi Academy of Science 16, 16–19.

Ernst, C.H., Lovich, J.E., Barbour, R.W., 1994. Turtles of the United States and Canada. Smithsonian Institution Press, Washington, DC.

Flaherty, N., Bider, J.R., 1984. Physical structures and the social factor as determinants of habitat use by *Graptemys geographica* in southwestern Quebec. American Midland Naturalist 111, 259–266.

Fuselier, L., Edds, D., 1994. Habitat partitioning among three sympatric species of map turtles, genus *Graptemys*. Journal of Herpetology 28, 154–158.

Gibbons, J.W., Lovich, J.E., 1990. Sexual size dimorphism in turtles with emphasis on the slider turtle (*Trachemys scripta*). Herpetological Monographs 4, 1–29.

Hammond, K.A., Spotila, J.R., Standora, E.A., 1988. Basking behavior of the turtle *Pseudemys scripta*: effects of digestive state, acclimation temperature, sex, and season. Physiological Zoology 61, 69–77.

Jones, R.L., 1996. Home range and seasonal movements of the turtle *Graptemys flavimaculata*. Journal of Herpetology 30, 376–385.

Jones, R.L., Hartfield, P.D., 1995. Population size and growth in the turtle *Graptemys oculifera*. Journal of Herpetology 29, 426–436.

Kofron, C.P., 1991. Aspects of ecology of the ringed sawback turtle, *Graptemys oculifera*. Amphibia-Reptilia 12, 161–168.

Kramer, M., 1995. Home range of the Florida red-bellied turtle (*Pseudemys nelsoni*) in a Florida spring run. Copeia 1995, 883–890.

Lamb, T., Lydeard, C., Walker, R.B., Gibbons, J.W., 1994. Molecular systematics of map turtles (*Graptemys*): a comparison of mitochondrial restriction site versus sequence data. Systematic Biology 43, 543–559.

Lindeman, P.V., 1993. Aerial basking by hatchling freshwater turtles. Herpetological Review 24, 84–87.

Lindeman, P.V., 1996. Distribution, relative abundance, and basking ecology of the razorback musk turtle, *Kinosternon carinatum*, in the Pearl and Pascagoula River drainages. Herpetological Natural History 4, 23–34.

Lindeman, P.V., 1997a. Effects of competition, phylogeny, morphology, and ontogeny on structuring the resource use of freshwater turtles. Ph.D. thesis, University of Louisville, Louisville, KY.

Lindeman, P.V., 1997b. A comparative spotting-scope study of the distribution and relative abundance of river cooters (*Pseudemys concinna*) in western Kentucky and southern Mississippi. Chelonian Conservation and Biology 2, 378–383.

Lovich, J.E., McCoy, C.J., 1992. Review of the *Graptemys pulchra* group (Reptilia: Testudines: Emydidae), with descriptions of two new species. Annals of the Carnegie Museum 61, 293–315.

Lydeard, C., Mayden, R.L., 1995. A diverse and endangered aquatic ecosystem of the southeast United States. Conservation Biology 9, 800–805.

McCoy, C.J., Vogt, R.C., 1979. Distribution and population status of the ringed sawback (*Graptemys oculifera*), blotched sawback (*Graptemys flavimaculata*), and black-knobbed sawback (*Graptemys nigrinoda*), in Alabama and Mississippi. US Fish and Wildlife Service, Jackson, MS.

Mills, M.S., Hudson, C.J., Berna, H.J., 1995. Spatial ecology and movements of the brown water snake (*Nerodia taxispilota*). Herpetologica 51, 412–423.

Moll, D., 1976. Food and feeding strategies of the Ouachita map turtle (*Graptemys pseudogeographica ouachitensis*). American Midland Naturalist 96, 478–482.

Moll, E.O., Legler, J.M., 1971. The life history of a neotropical slider turtle, *Pseudemys scripta* (Schoepff), in Panama. Bulletin of the Los Angeles County Museum of Natural History, Science 11, 1–102.

Pluto, T.G., Bellis, E.D., 1986. Habitat utilization by the turtle, *Graptemys geographica*, along a river. Journal of Herpetology 20, 22–31.

Sanderson, R.A., 1974. Sexual dimorphism in the Barbour's map turtle, *Malaclemmys barbouri* (Carr and Marchand). M.A. thesis, University of South Florida, Tampa, FL.

Seigel, R.A., Brauman, R.J., 1994. Food habits of the yellow-blotched map turtle (*Graptemys flavimaculata*). Mississippi Museum of Natural Science Technical Report 28.

Shively, S.H., Jackson, J.F., 1985. Factors limiting the upstream distribution of the Sabine map turtle. American Midland Naturalist 114, 292–303.

Stewart, J., 1986. Proposed threatened status for the ringed sawback turtle. Federal Register 51, 2741–2744.

Stewart, J.H., 1991. Proposed threatened status for the yellow-blotched map turtle, *Graptemys flavimaculata*. Federal Register 55, 28 570–28 573.

Tinkle, D.W., 1958. The systematics and ecology of the *Sternothaerus carinatus* complex (Testudinata, Chelydridae). Tulane Studies in Zoology 6, 3–56.

US Fish and Wildlife Service, 1988. Ringed sawback turtle recovery plan. US Fish and Wildlife Service, Jackson, MS.

US Fish and Wildlife Service, 1993. Yellow-blotched map turtle (*Graptemys flavimaculata*) recovery plan. US Fish and Wildlife Service, Jackson, MS.

Vogt, R.C., 1979. Cleaning/feeding symbiosis between grackles (*Qu. us*: Icteridae) and map turtles (*Graptemys*: Emydidae). Auk 96, 608–6

Vogt, R.C., 1980a. New methods for trapping aquatic turtles. Copeia 1980, 368–371.

Vogt, R.C., 1980b. Natural history of the map turtles *Graptemys pseudogeographica* and *G. ouachitensis* in Wisconsin. Tulane Studies in Zoology and Botany 22, 17–48.

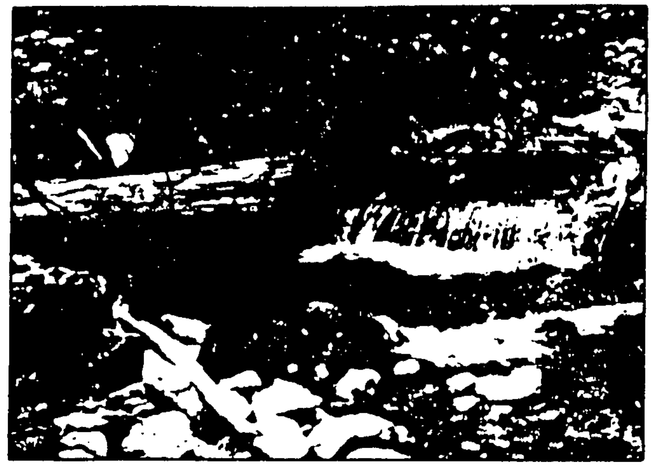
Vogt, R.C., 1981. Food partitioning in three sympatric species of map turtle, genus *Graptemys* (Testudinata, Emydidae). American Midland Naturalist 105, 102–111.

Waters, J.C., 1974. The biological significance of the basking habit in the black-knobbed sawback, *Graptemys nigrinoda* Cagle. M.S. thesis, Auburn University, Auburn, AL.

Removal of Woody Debris May Affect Stream Channel Stability

Robert E. Bilby

ABSTRACT—Several western states mandate the removal of logging debris from streams in order to prevent accumulations impassable to anadromous fish. Monitoring a small western Washington stream revealed large changes in channel structure during the first high flow after cleaning. Nearly 60 percent of the monitored pieces of debris moved during this storm, channel cross sections were substantially altered by movement of stored sediment, and the number, area, and volume of pools decreased. The degree of channel rearrangement was greater than in a comparable undisturbed stream. Subsequent storms caused much less debris movement and channel change than the first high flow, even though some of the later flows were of greater magnitude. An interim guide to stream cleaning is precribed.



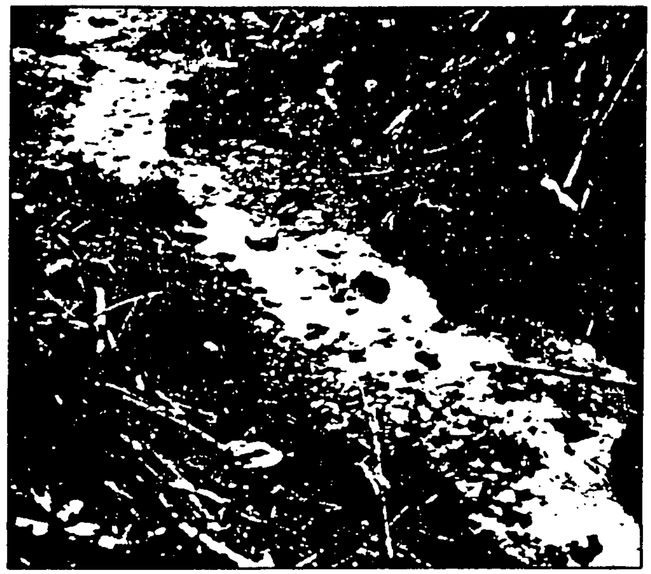


Figure 1. Top—Salmon Creek before logging. Bottom—A stretch of the creek after channel cleaning.

...ge woody debris in the channel influences both the ...l and biological processes occurring within a stream. The influence on channel morphology and the routing of sediment has been amply demonstrated. Woody debris also traps organic matter, such as leaves and needles, which often forms a substantial portion of the energy base of a stream (Fisher and Likens 1973). In first-order streams in central New Hampshire, for example, 75 percent of the organic matter larger than 1 mm in size was associated with accumulations of woody debris (Bilby and Likens 1980). This value decreased to 58 percent in second-order streams and 20 percent in third-order streams as the frequency of debris accumulations declined.

Debris forms an important component of cover for fish (Lewis 1969). In an Alaskan stream, the population of Dolly Varden char decreased 80 percent after debris removal, presumably because of the loss of suitable cover (Elliott 1979). Anadromous fish may also be influenced by debris when it blocks access to spawning and rearing habitat.

In undisturbed ecosystems, woody debris enters streams in a random fashion, usually as a result of windthrow. Pieces which have recently entered may deflect water, causing localized destabilization of banks or bed (Zimmerman et al. 1967). Debris entry ordinarily is rare, and thus the channel changes are of limited extent. In some instances, however, such as catastrophic blowdown, a long reach of stream channel may be affected.

...ce logging may increase the amount of woody debris ...nels, regulatory agencies in Washington and Oregon c...tly mandate stream cleaning during or after timber harvesting. Just as new debris can destabilize a channel, so can the removal of old debris around which the channel has equilibrated (Bilby 1981). While the guidelines in both states stipulate that such older debris be left in the stream, identification of this material is sometimes difficult and often some of it is removed. Even if an old piece is left, it is very often altered by bucking or notching for fish passage.

This article describes changes in channel morphology and the movement of woody debris after logging and subsequent channel cleaning in a stream in western Washington. In addition, the characteristics of those pieces which remained stable after cleaning were determined.

Instream Measurements

The stream was Salmon Creek (*fig. 1*), a fourth-order tributary to the Chehalis River in the Coast Range of Washington; Salmon Creek drains a watershed of approximately 900 ha. Some of the headwater areas were harvested about 25 years ago, but the lower watershed, including the 600m section studied as the basis for this article, was unlogged prior to 1980. Salmon Creek contains native cutthroat trout (*Salmo clarki*) and sculpins (*Cottus* spp.) as well as occasional steelhead (*Salmo gairdneri*) and coho salmon (*Oncorhynchus kisutch*) in the lower reaches. The section studied has an average bankful channel width of 11.5 m and an average gradient of 1.5 percent.

The section bordering the study reach was logged during ıe late winter and early spring of 1980. During the summer, the channel was cleaned in accordance with the state rest practice regulations (Washington State Forest Pracce Board 1976). Debris was bucked into pieces small ıough to be moved by hand and piled along the bank. any of the large pieces left in the channel were notched or ıcked, or had gaps cut in them, to facilitate the upstream ovement of fish. Seventy-four remaining pieces were gged and monitored throughout the winter of 1980–81. ɔproximately equal numbers of pieces were tagged in ch of four length and four diameter classes.

Data on each tagged piece included the diameter and ıgth, degree of anchoring or burial (including keying of e ends of the log into the banks and the extent of burial the upstream face of the log), and distance to established ·eam bank reference markers.

After each high flow during the winter of 1980–81 the ;ged pieces were relocated and their positions remeasured. ıce high flow carried some out of the study section, 500 m stream below the study reach were examined on each ocation date. Approximately 20 percent of the tagged ces of debris were lost over the winter, being either ried out of the monitored area or buried somewhere on study reach.

Changes in channel configuration were monitored over winter by two independent methods. Ten channel cross tions were installed during June 1980. These were ıeasured in November 1980, after the first high flow owing the channel cleaning and again in January 1981, r very high flow during late December 1980. In addiı, detailed maps of channel configuration were drawn for 25m stretch of the study section in July 1980, mid-ember 1980, and January 1981 (Bisson et al. 1982). se maps indicated the frequency, area, and volume of ls and riffles and differentiated between pools formed by dy debris and those associated with other channel ures.

he degree of channel rearrangement occurring on non Creek during this period was compared with that ı 260m undisturbed headwater section of Fall River, her coastal stream approximately 30 km north of non Creek. This section of Fall River is similar in size morphology to Salmon Creek, draining approximately 0 ha. Channel width averaged 7.6 m and gradient 1.6 ent. Nine cross sections were measured in fall 1980 and n in spring 1981. The stream was mapped in summer and again in December 1980.

› monitor streamflow on Salmon Creek, a gauging sta-was constructed just upstream from its mouth. A r level recorder provided a continuous record of disge. Peak flows, which were of primary importance in study, were quantified and the resultant debris move-: or channel changes interpreted in relation to their ııitude.

Movement of Residual Debris

e most extensive debris movement observed in Salmon k during the winter coincided with the first period of flow after cleaning, when nearly 60 percent of the ɜd pieces moved *(fig. 2)*. This storm was not particusevere, its discharge peaking at 6.76 m³/s. In contrast, ıs producing flows of similar magnitude in late No-er 1980 and mid-February 1981 induced movement of ɜrcent or less of the tagged pieces. A large storm of

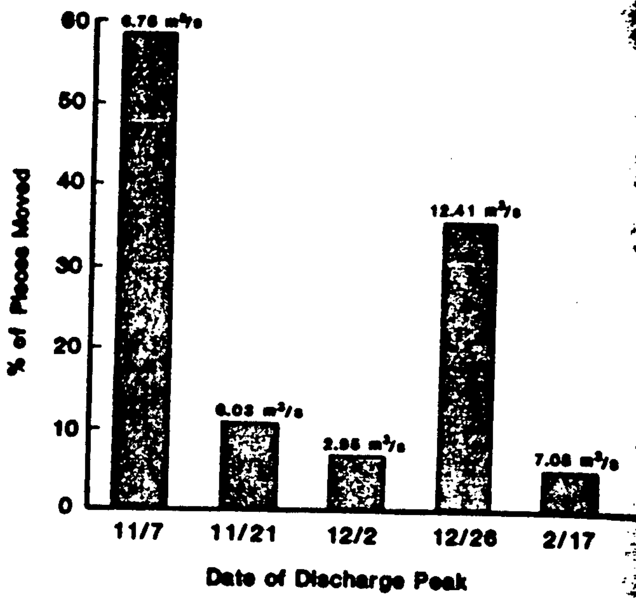


Figure 2. Percent of marked pieces of woody debris which moved during each high flow period on Salmon Creek during winter 1980–81.

December 26, 1980, resulted in the highest peak flow of the winter. The discharge on this date was 84 percent higher than the initial period of high discharge on November 7, and had a calculated return interval of about 7 years. About 35 percent of tagged pieces moved as a result of this storm.

The debris movement during the November 7 storm was in large part caused by the cleaning. Movement of pieces, or modification of their influence by bucking or notching, altered flow patterns and in turn moved other debris that previously was in stable locations.

Debris moved downstream until it was deposited in a stable location, generally either on the streambank or against some channel obstruction such as a bedrock outcrop, boulders, or other debris. Pieces thus deposited remained in place through lesser discharges of November 21 and December 12.

The flow on December 26 was considerably higher than that on November 7 and some debris that had been stable at lesser flows was moved again. The deposition during this storm was presumably in locations resistant to movement at lesser flows. Indeed, the high flow during mid-February 1981 had very little influence on the debris.

Changes in Channel Form

The first high flow during winter 1980–81 also modified the channel by triggering scour and fill. During the large December storm substantial additional scour took place as sediments released by the channel cleaning began to move. Reaches downstream from the study section probably experienced a cycle of fill and scour as the wave of material migrated.

The net changes in the channel cross sections on Salmon Creek over the winter of 1980–81 are shown in *table 1*. The general pattern is a scouring and lowering of the bed, probably due to the removal or alteration of debris that was retaining sediment. By comparison to Fall River, the difference in bed elevation change over winter 1980–81 is striking. Beds changed an average of 25.4 cm per cross section in Salmon Creek but only 3.3 cm in Fall River. None of the Fall River cross sections changed more than 9

Table 1. Cro

Cross section
1
2
3
4
5
6
7
8
9
10
Average* eleva change per c

*Average elevatic

Table 2. Cha 1980–81, as cated dates.

Item
Number of poc
Pools eliminate since last m
Pools formed since last m
Percent of poc formed by d
Percent area i
Percent volume in p
Number of riff
Riffles eliminat since last m
Riffles formed since last m
Percent of stre area in riffle
Percent of stre volume in ri

·m over the ·xcess of th of scour on

Comparis ary 1981 ch changes ove high flow re Seventeen p ing of the st Of the 22 p with large ·n pool nur ·ncrease in creased larg previously The i change *(table 2)* these 8 poo in number caused by t

Table 1. Cross-section changes 1980–81. Negative numbers indicate scour, positive numbers indicate fill.

Cross section	Salmon Creek: Change in bed elevation, June–Nov. 14, 1980	Nov. 15, 1980–Jan. 11, 1981	Net 1980–81	Fall River: Cross section	Change in bed elevation, 1980–81
	Cm				Cm
1	11.11	−7.41	3.70	1	0.0
2	.0	−13.61	−13.61	2	−8.19
3	−20.50	17.46	−3.04	3	2.37
4	29.38	−4.90	24.48	4	−8.67
5	37.50	−14.20	23.30	5	.0
6	−8.73	−16.21	−24.93	6	1.67
7	−11.11	−24.44	−35.55	7	−1.36
8	−14.20	−65.99	−80.19	8	6.11
9	.0	2.74	2.74	9	−1.15
10	1.16	−27.91	−26.75		
Average[a] elevation change per cross section	14.19	19.43	25.41		3.28

[a]Average elevation change values include both scour and fill numbers as positive values.

Table 2. Changes in channel morphology during winter 1980–81, as determined from maps made on the indicated dates.

Item	Salmon Creek 7/17/80	Salmon Creek 12/12/80	Salmon Creek 1/6/81	Fall River 6/24/80	Fall River 12/19/80
Number of pools	29	17	19	22	24
Pools eliminated since last mapping	—	17	3	—	2
Pools formed since last mapping	—	5	5	—	4
Percent of pools formed by debris	86	77	79	73	71
Percent of stream area in pools	50	32	39	70	74
Percent of stream volume in pools	72	46	63	85	87
Number of riffles	33	26	31	16	14
Riffles eliminated since last mapping	—	12	10	—	6
Riffles formed since last mapping	—	5	15	—	4
Percent of stream area in riffles	50	68	61	30	26
Percent of stream volume in riffles	28	54	37	15	13

cm over the winter, while Salmon Creek showed changes in excess of this on 8 of 11 cross sections and exhibited 80 cm of scour on one cross section.

Comparison of the July 1980, December 1980, and January 1981 channel maps of Salmon Creek also showed major changes over the winter of 1980–81 *(table 2)*. The initial high flow reduced the number, area, and volume of pools. Seventeen pools were eliminated, either by filling or rerouting of the stream channel, and five new pools were formed. Of the 22 pools affected by this storm, 20 were associated with large woody debris. Concurrent with the reduction in pool number, area, and volume was a corresponding increase in riffle area and volume. Number of riffles decreased largely because pool elimination joined two or more previously separated riffles into one continuous riffle.

The intense storm of December 26 caused lesser channel changes than those observed during the initial high flow *(table 2)*. Five pools were formed and 3 were eliminated. Of these 8 pools, 4 were associated with debris. The increase in number of pools was not sufficient to offset the changes caused by the initial high flow.

The importance of large pieces of wood in forming pools was apparent on this stretch of Salmon Creek. In July 1980, immediately after stream cleaning, 86 percent of the pools were associated with woody debris. Even after rearrangement of the channel by the winter storms, in excess of 75 percent of the pools were debris-related as were 24 of the 30 pools that were formed or eliminated over the winter.

Woody debris was also important on Fall River, forming or significantly influencing more than 70 percent of the pools on the study stretch. This debris was generally stable, with 2 pools eliminated and 4 formed (as compared with 17 pools eliminated and 5 formed on Salmon Creek during the early fall period of high flow). Riffles were less stable than pools on Fall River; during the initial period of high flow 10 were formed or eliminated as compared with 15 on Salmon Creek.

The major change seen on Salmon Creek as a result of channel cleaning and high flow was a reduction in the frequency of pools formed by woody debris. The alteration or removal of debris during the stream cleaning and the subsequent movement of the debris and sediment during the initial high flow after the cleaning eliminated many of the pools. Once the debris was deposited in stable locations and again began to function in control of flow, pools began to reform, as seen by the increase in pool frequency and area following the high flow of December 26. Additional periods of high flow may cause a further increase in pool frequency as the stream equilibrates with the remaining debris. However, the overall reduction in the amount of large woody debris in this stream section may preclude complete reestablishment of the pool and riffle composition that existed before the cleaning.

Characteristics of Stable Woody Debris

The immediate effects of debris alteration or removal on channel stability could be reduced by minimizing changes to pieces that are determining channel morphology. Unstable debris, such as tree tops or branches which enter during logging, should be removed to lessen its accumulation in barriers that cannot be surmounted by anadromous fish. In

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efining what constitutes stable debris, this study indicates hat size and degree of anchoring are the most important. 'he propensity of a piece to move during high flow was osely related to its length *(fig. 3A)*. Pieces less than 2.5m ng moved readily while those longer than 10.0 m rarely ioved. The long pieces were usually stabilized at several oints along their length by stream banks or channel ob-.ructions. Diameter of a piece also influenced the probabil-y of its moving *(fig. 3B)*. Pieces more than 50 cm in iameter moved much less frequently than smaller pieces, nce deeper water was needed to float them.

Length of debris was inversely related to the distance aveled by those pieces which moved. Average distance oved was 129 m for pieces in the 0–2.5m class, 99 m for eces from 2.6–5.0 m, 54 m for pieces from 5.1–10.0 m, and m for pieces longer than 10 m. This relationship is likely used by the increased chance a longer piece has for icountering an obstruction that will hold it in place. The ameter classes, however, showed no relationship to dis-nce traveled. Movement averaged 110 m for pieces from –25 cm, 113 m for 25–50cm pieces, 106 m for 50–75cm eces, and 106 m for pieces larger than 75 cm. Generally, e large-diameter debris that moved during the winter had en cut into short chunks.

The relative degree of anchoring or burial also influences e stability of debris *(fig. 4)*. Pieces not anchored in the d or banks were apt to move during high flows. Anchor-g one end or the face of the log greatly reduced the obability of movement. Pieces having both ends and their stream face buried in the stream banks and bed did not ve.

Stream Debris Management Guidelines

This study demonstrated that indiscriminant removal of ge woody debris has major short-term influences on annel stability. Loss in stability may have adverse effects fish populations. To preserve channel integrity and intain stream productivity, pieces influencing channel rphology should be left in place during cleaning. The idy further identified features that contribute to debris bility in the stream channel. Knowledge of the size and ier features common to stable debris in streams of vari-s sizes and characteristics might provide the basis for nagement guidelines designed to protect stream produc-ity better than do current procedures. As an interim asure, here are cleaning guidelines based on this study. must be stressed that they are applicable only to streams iilar to Salmon Creek. They refer to all debris impinging any way on the channel, regardless of the proportion of piece extending out of the stream.

emove all slash (branches and tops) from bankful stream channel.

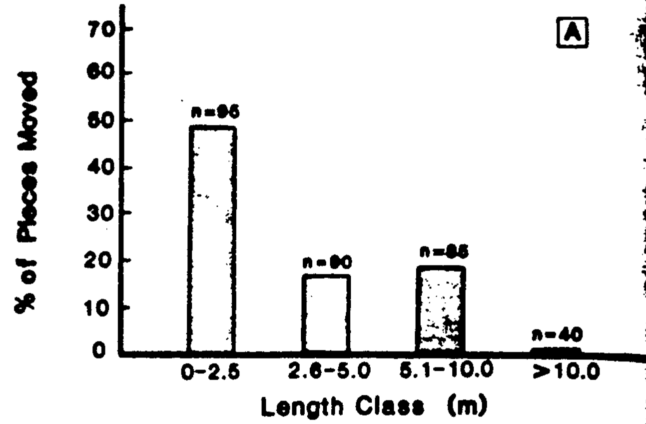
o not remove pieces of debris conforming to the specifi-cations in the key below.

o not buck, notch, or move any pieces that will be left in the stream.

Debris Stability Key

ise as a dichotomous key starting with couplet 1):

a) Debris anchored or buried in the streambed or bank at one or both ends or along the upstream face—LEAVE.
b) Debris not anchored—2.
a) Debris longer than 10.0 m—LEAVE.
b) Debris shorter than 10.0 m—3.



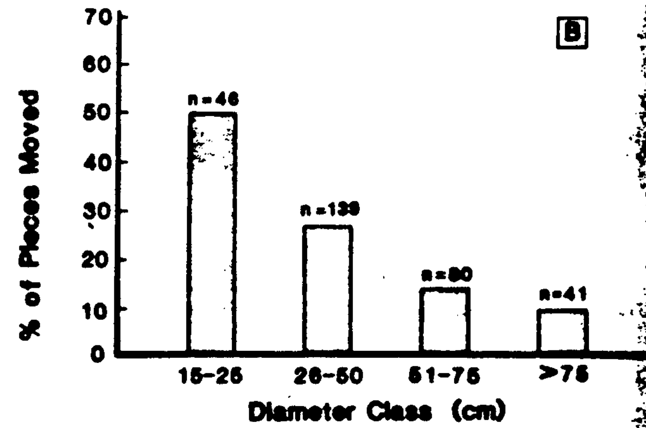


Figure 3A. Percent of the tagged pieces of debris which moved during winter 1980–81 on Salmon Creek as related to length of the debris. The number of observations made in each class over the winter is listed at the top of the bars. 3B. Percent of the tagged pieces of debris which moved during winter 1980–81 on Salmon Creek as related to diameter of the debris. The number of observations made in each class over the winter is listed at the top of the bars.

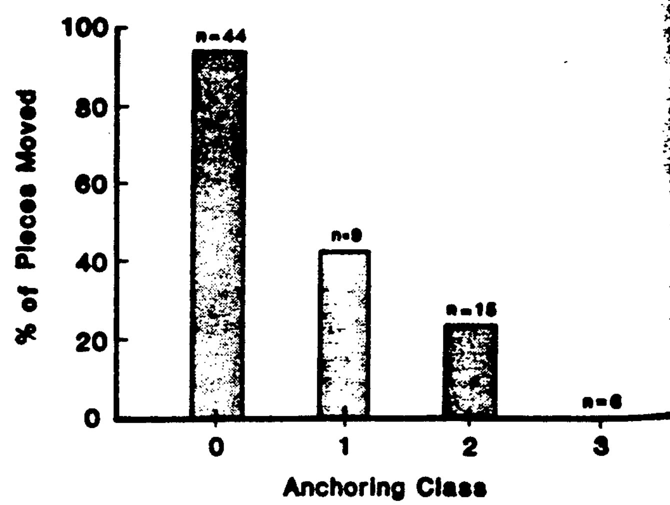


Figure 4. Percent of the tagged pieces of debris which moved during winter 1980–81 on Salmon Creek as related to anchoring of the debris. Anchoring classes were determined as follows: (0) no burial; (1) one end or face of debris buried; (2) both ends or one end and face buried; (3) both ends and face buried. The number of observations made in each size class over the winter is listed at the top of the bars.

3) a) Debri
b) Debr
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ABSTRACT (98 percent was applied uninfested modified a measu cient sugae) inf. MCH treat rufipennis) windthrown

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Thinning windthrow vindthrow other value be needed natural an 1-one (MC enou serves competitio Since 1

3) a) Debris greater than 60 cm in diameter—4.
   b) Debris less than 60 cm in diameter—5.

4) a) Debris longer than 5.0 m—LEAVE.
   b) Debris shorter than 5.0 m—5.

5) a) Debris braced on downstream side by boulders, bedrock outcrops, or stable pieces of debris—LEAVE.
   b) Debris not braced on downstream side—REMOVE. ■

Literature Cited

BILBY, R.E. 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. Ecology 62:1234–1243.

BILBY, R.E., and G.E. LIKENS. 1980. Importance of organic debris dams in
the structure and function of stream ecosystems. Ecology 61:1107–1113.

BISSON, P.A., J.L. NIELSEN, R.A. PALMASON, and L.E. GROVE. 1982. A
system of naming habitat types in small streams, with examples of habitat
utilization by salmonids during low streamflow. P. 62–73 in N.B.
Armantrout, ed., Acquisition and Utilization of Aquatic Habitat Inventory
Information. Western Div., Am. Fish. Soc.

ELLIOTT, S.T. 1979. Ecology of rearing fish. Annual Performance Rep.
Alaska Dep. Fish and Game, vol. 19, study 01B, p. 39–52.

FISHER, S.C., and G.E. LIKENS. 1973. Energy flow in Bear Brook, New
Hampshire: an integrative approach to ecosystem metabolism. Ecol.
Monogr. 43:421–439.

LEWIS, S.L. 1969. Physical factors influencing fish populations in pools of a
trout stream. Trans. Am. Fish. Soc. 98:14–19.

WASHINGTON FOREST PRACTICE BOARD. 1976. Washington forest practice
rules and regulations. Olympia, WA. 54 p.

ZIMMERMAN, R.C., J.C. GOODLET, G.H. COMER. 1967. The influences of
vegetation on channel form of small streams. P. 255–275 in Proc. Symp.
River Morphology. Int. Assoc. Sci. Hydrol., Publ. 75.

MCH Pheromone for Preventing Douglas-Fir Beetle Infestation in Windthrown Trees

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Kenneth E. Gibson, and Hubert E. Meyer

ABSTRACT—A granular controlled-release formulation (98 percent inert, 2 percent 3-methyl-2-cyclohexen-1-one) was applied May 11–13, 1982, at 4.48 kg/ha to 76.9 ha of uninfested windthrown Douglas-fir by helicopter with a modified aerial spreader of 1.13 m^3 capacity. Granules measured on treated plots averaged 2.04–2.69 kg/ha, sufficient to reduce Douglas-fir beetle (Dendroctonus pseudotsugae) *infestation 96.4 percent by late June. The same MCH treatment reduced spruce beetle* (Dendroctonus rufipennis) *attacks by 55 percent in fewer, intermingled windthrown Engelmann spruce.*

The Douglas-fir beetle (DFB) is an important bark beetle, infesting Douglas-fir throughout most of that tree's extensive range in western North America. Trees felled by wind or top-broken by snow are prime hosts for buildups of the insect (Furniss et al. 1981b). The extent to which enlarged populations kill standing trees depends upon availability of dense, mature Douglas-fir stands. Stand susceptibility is increased by drought and defoliation by the Douglas-fir tussock moth *(Orgyia pseudotsuga)* and sometimes the western spruce budworm *(Choristoneura occidentalis)*. In mature trees, infestation by low populations of DFB is correlated with root diseases; the correlation is less strong during DFB outbreaks.

Thinning of susceptible stands and salvage of fresh windthrow will prevent tree-killing by beetles. But where windthrown trees are inaccessible, or where aesthetic or other values preclude thinning or logging, other means may be needed. One such alternative is to use the beetles' natural antiaggregative pheromone, 3-methyl-2-cyclohexen-1-one (MCH). In nature, MCH terminates attraction after enough beetles have aggregated to overcome a tree; it thus serves to forestall overcolonization and consequent lethal competition among broods.

Since 1972, we have been working to develop synthetic

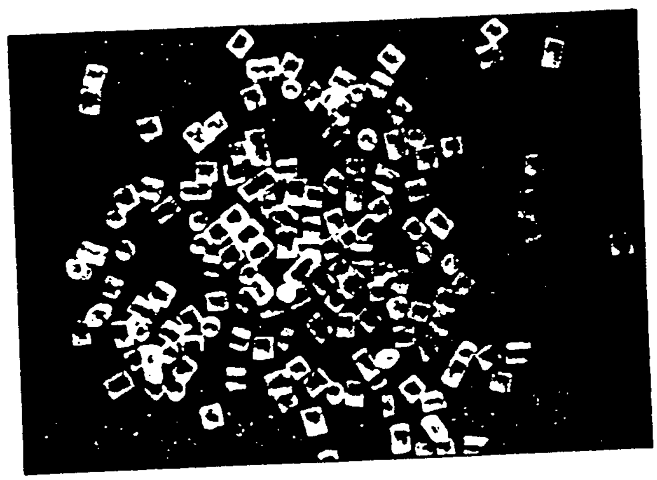

Figure 1. The antiaggregative pheromone, MCH, was time-released from inert rod-shaped granules to prevent beetles from breeding in windthrown trees.

MCH as a means of preventing outbreaks by denying beetles windthrown trees. Beetles must then cope with a more hostile environment, including increased predation and the resistance of live trees.

A granular controlled-release formulation *(fig. 1)* containing 2-percent MCH and 98-percent inert dimer acid polyamide beads (U.S. Patent 4,170,631) has been effective in tests on trees felled to simulate windthrow (Furniss et al. 1977). When applied by helicopter with a modified aerial spreader at ground-measured rates of 1.41–9.80 kg/ha, it reduced DFB attack density 92–97 percent (Furniss et al. 1981a).

In November 1981, strong winds blew down thousands of trees in Idaho forests, setting the stage for outbreaks of DFB as well as the spruce beetle *(Dendroctonus rufipennis)* which breeds prolifically in windfelled Engelmann spruce *(Picea engelmannii)* (Schmid and Frye 1977). This event

Quantification of Wood Habitat in Subtropical Coastal Plain Streams

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Wallace, J. B., and A. C. Benke. 1984. Quantification of wood habitat in subtropical Coastal Plain streams. Can. J. Fish. Aquat. Sci. 41: 1643–1652.

To assess the importance of woody debris in two relatively unaltered Coastal Plain streams in the southeastern United States, a line intersect technique, developed by foresters, was used to estimate volume, mass, surface area, and spatial distribution. The ash-free dry mass of in-channel woody material was 6.5 kg/m^2 of stream channel bottom in the sixth-order Ogeechee River and 5.0 kg/m^2 in the fourth-order Black Creek. Most wood is located near the erosional bank in these meandering streams. These wood mass estimates are much higher than expected for middle-order streams and are similar to those from several small headwater streams in other regions. Due to their very low slopes (<0.02%), these streams appear to have insufficient stream power to move large woody material. Snag, or woody, habitat is the major stable substrate in these sandy-bottomed streams and is a site of high invertebrate diversity and productivity. In-channel snag surface area per square metre of channel bottom was 0.249–0.433 m^2 in the Ogeechee and 0.191–0.379 m^2 in Black Creek, depending on the hydrograph stage. With invertebrate biomass of 6.6 g dry mass/m^2 of snag surface, this results in an invertebrate biomass of at least 1.88 g/m^2 of channel bottom. Wood is also important to fishes, providing a rich source of invertebrate food, habitat, and cover. In addition to its obvious biological role, wood enhances the ability of a stream to process and conserve nutrient and energy inputs and has a major influence on the hydrodynamic behavior of the river. The quantification of wood habitat seems mandatory to assess past or potential impacts of snag removal on ecosystem processes in low-gradient streams.

Pour évaluer l'importance des débris ligneux dans deux cours d'eau de plaine côtière relativement inaltérés dans le Sud-Est des États-Unis, une technique d'échantillonnage linéaire, mise au point par des forestiers, a été employée pour estimer le volume, la masse, la superficie et la répartition spatiale. La masse sèche sans cendres de matière ligneuse dans le chenal était de 6,5 kg/m^2 de fond de chenal dans la rivière Ogeechee (6^e ordre) et de 5,0 kg/m^2 dans le ruisseau Black (4^e ordre). Presque tout le bois est situé près de la berge d'érosion dans ces cours d'eau sinueux. Ces estimations de la masse de bois sont beaucoup plus élevées que prévu pour des cours d'eau d'ordre moyen et elles sont analogues à celles qui proviennent de plusieurs petits cours d'eau (près de leur source), dans d'autres régions. En raison de leurs pentes très faibles (<0,02%), ces cours d'eau semblent posséder une force hydraulique insuffisante pour déplacer de grandes quantités de matière ligneuse. L'habitat du bois canard ou de la matière ligneuse correspond au principal substrat stabilisé dans ces cours d'eau à fond sableux et c'est le site d'une grande diversité et d'une grande productivité d'invertébrés. La superficie occupée par le bois canard, par mètre carré de fond de chenal, était de 0,249–0,433 m^2 dans la Ogeechee et de 0,191–0,379 m^2 dans le ruisseau Black, suivant le stade de l'hydrogramme. Avec une biomasse d'invertébrés de 6,6 g de masse sèche/m^2 de surface occupée par du bois canard, ceci produit une biomasse d'invertébrés d'au moins 1,88 g/m^2 de fond de chenal. Le bois est aussi important pour le poisson, puisqu'il fournit une source abondante d'aliments, un habitat et une couverture pour les invertébrés. Outre ses fonctions biologiques évidentes, le bois augmente la capacité qu'a un cours d'eau de traiter et de conserver les apports en matière nutritive et en énergie ; il a donc une influence considérable sur le comportement hydrodynamique de la rivière. La quantification de l'habitat boisé semble s'imposer pour évaluer les répercussions possibles de l'enlèvement du bois canard sur les processus de l'écosystème dans les cours d'eau à faibles gradients.

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Large woody debris, or snags, has been removed from rivers, especially low-gradient rivers, for centuries in efforts to create navigable waterways. Since such practices long preceded ecological investigations, the significance of wood in the structure and function of riverine ecosystems has not been widely appreciated. Many headwater streams are strongly influenced by the allochthonous inputs, primarily leaves, from their catchments (Cummins 1974; Hynes 1975). Woody debris also represents an input that may play an extremely important structural role in small streams (Marzolf 1978; Sedell et al. 1982). The purpose of this paper is to assess

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the importance of wood in larger (greater than third-order) streams, particularly as a habitat for invertebrates.

The importance of wood has been well documented in low-order streams with a relatively high gradient, including streams in New England (Bilby and Likens 1980), Oregon (Anderson and Sedell 1979; Naiman and Sedell 1979a; Triska and Cromack 1980), New Mexico (Molles 1982), southern Appalachians (Wallace et al. 1982), and some in New Zealand (Rounick and Winterbourne 1983). Woody debris has many diverse roles in headwater streams, such as rapid dissipation of the stream's energy (Bilby and Likens 1980); retention of other allochthonous organic matter (e.g. Bilby and Likens 1980), which influences both trophic and nutrient dynamics (e.g. Bilby 1981; Newbold et al. 1982; Melillo et al. 1983); providing valuable fish habitat (e.g. Marzolf 1978; Triska and Cromack 1980; Sedell et al. 1982); substrate for many stream invertebrates (e.g. Nilson and Larimore 1973; Anderson et al. 1978; Marzolf 1978); and food for some species of aquatic insects, which appear to be primarily xylophagous (Anderson et al. 1978; Anderson and Sedell 1979; Dudley and Anderson 1982; Pereira et al. 1982).

Vannote et al. (1980) predicted that the effect of riparian vegetation becomes insignificant in medium to larger (greater than fifth-order) streams, as either in-stream primary production or upstream inputs of fine particulate organic matter provide the major sources of energy. It logically follows that woody debris should play a minor role in larger streams as well. In larger streams of the Pacific Northwest (United States), woody debris is found in the riparian zone or deposited along river banks, but apparently plays a minor role in habitat formation in the main channel (Keller and Swanson 1979; Triska and Cromack 1980). The reduction in wood with increasing stream order appears to be true in streams greater than fifth order from a variety of biomes in which there are moderate to high stream gradients (0.09–0.6%) (Minshall et al. 1983).

In contrast with the findings of Minshall et al. (1983) and others, wood appears to be a major structural feature in middle-order streams (fourth to seventh) of the southeastern Coastal Plain. In these very low gradient streams (0.01–0.02% slope), "snag" substrates are important habitats for macroinvertebrates and sites of high secondary production (Cudney and Wallace 1980; Benke et al. 1984). Woody material affords a relatively stable habitat compared with the unstable, fine-grain sandy substrate that is characteristic of Coastal Plain streams. Furthermore, several species of game fish forage almost exclusively on invertebrates associated with these woody substrates (Benke et al. 1979; Benke et al., unpubl. data.). Submerged wood plays a similar role in many of the larger streams of the Amazon Basin (Fittkau et al. 1975; Fittkau 1982; Sioli 1982), and it may be an important habitat in most low-gradient streams unless snagging operations are a part of their recent history. Sedell et al. (1982) suggested that wood was a major structural feature of many large rivers before man removed this material for navigational purposes.

The major objective of this study was to provide estimates of woody debris and its spatial distribution in two middle-order (fourth and sixth) southeastern Coastal Plain streams. To accomplish this objective requires estimates of wood volume and mass, which are important from a structural standpoint, and wood surface area, which is the most appropriate measure of available invertebrate habitat.

Study Sites

The Ogeechee River has a drainage basin of 14 335 km^2 and flows southeasterly across the Coastal Plain to the Atlantic Ocean. The total length from origin to mouth, about 24 km south of Savannah, GA, is about 390 km. The study site is located about 63 river km from the mouth at an elevation of approximately 6.1 m a.s.l. where the sixth-order river drains an area of approximately 7000 km^2. Average annual precipitation over the basin is 117 cm, and average basin runoff is approximately 28 cm. There is little topographic relief at the study site. stream gradient is 19.6 cm/km, and the river meanders within a broad, heavily forested, lowland flood plain swamp, exceeding 1 km in width on either bank of the stream. Mean channel width is 33 m. Mean annual discharge at the study site is 67.7 m^3/s with long-term extremes approximately 850 m^3/s (1936) and 3.7 m^3/s (1954) (United States Geological Survey 1982).

The wide forested flood plain of the Ogeechee forms a buffer strip between the river and both farm lands and extensive pine forsts within the basin. The dominant trees associated with the banks and adjacent flood plain forest include baldcypress (*Taxodium distichum*), sweetgum (*Liquidambar styraciflua*), water oak (*Quercus nigra*), black gum (*Nyssa sylvatica*), water tupelo (*Nyssa aquatica*), willow (*Salix* spp.), and several pines (*Pinus* spp.). Willows dominate point bars whereas any of the other tree species may be found along the erosional banks of the meandering, convoluted path of the stream. The stream bed consists primarily of fine sandy substrate with some pebble and small gravel substrate in areas of higher velocity.

Black Creek is a fourth-order tributary of the Ogeechee. entirely located on the Coastal Plain, and drains an area of 767 km^2. Our study site is approximately 6.2 m a.s.l. with a drainage area of approximately 755 km^2 and a stream gradient of 29.8 cm/km. The flood plain varies from only a few metres in width, where forested bluffs rise 3–6 m in height above the stream, to 1.7 km in width. The bottom substrate consists primarily of white sand and occasional outcrops of sandstone. Mean stream width during low flow conditions is approximately 10 m; however, this width increases rapidly during rising water as sloping sand bars are inundated (bankfull width = approximately 21 m). Prior to 1980, Black Creek was gaged only periodically and discharge records range from zero flow (1954) to over 45 m^3/s (1980) (United States Geological Survey 1982). The Black Creek flood plain is also heavily forested, and with the exception of *Salix*, which is absent along Black Creek, dominant trees are similar to those of the Ogeechee.

Materials and Methods

In order to estimate wood volume and wood surface area, we utilized the line intersect technique, originally developed by Warren and Olsen (1964) to estimate logging residue. The theory of the method is explained by de Vries (1974). He pointed out that if a straight line of length L is run through a population of elements (such as logs), and if n elements intersect the vertical plane created by this line, then

$$(1)\quad \hat{X} = (\pi/2L) \sum^{n} X_i/l_i$$

is an unbiased estimator of the mean quantity of these elements per unit area, where X_i is the true value of any characteristic

(such as log volume) of the ith element and l_i is a uniquely defined length (such as log length) associated with that element. de Vries (1974) showed that an estimate of log volume per unit area can be derived from the above equation by substituting log volume, $(\pi/4)d^2_i l_i$, for X_i, where d_i is the diameter of a stem intersected by the line. This results in the expression

$$(2) \quad \hat{X}_v = (\pi^2/8L) \sum^n d_i^2.$$

Thus, for a transect of length L, all stem diameters d_i are measured and can be used to calculate the volume of wood per unit area. Notice that lengths of stems (l_i) do not need to be measured, since they cancel out in the equation. Van Wagner (1969) provided a clear discussion of the actual procedure for taking measurements, and he pointed out that the method assumes that all stems are lying on a horizontal surface. However, he showed that the error is less than 10% if the angle is 25°.

In order to estimate wood surface area, a second equation was derived based on the principles elucidated by de Vries (1974). The expression for the surface area of a cylinder, $X_i = \pi d_i l_i$, rather than volume, was substituted into equation 1 to obtain

$$(3) \quad \hat{X}_{sa} = (\pi/2L) \sum^n (\pi d_i l_i)/l_i.$$

Again, l_i's cancel out and the expression simplifies to

$$(4) \quad \hat{X}_{sa} = (\pi^2/2L) \sum^n d_i.$$

Sampling was conducted during the lowest stream discharge possible, when wood can be measured accurately and safely. To determine the horizontal distribution of wood, a nylon line marked at 1-m intervals was stretched across the stream channel at a height 1 m above the water surface, and stem diameters (both living and dead) were tabulated within each metre mark along the transect. Depth was measured every 2 m along each transect in the Ogeechee and every 1 m in Black Creek. Stem diameters were tabulated at three heights: below the water surface, 0–1 m above the surface, and 1–2 m above the surface. The 2-m elevation was near the height of the bank and therefore, sampling above 2-m elevation was not feasible. However, stem abundance within the channel decreases considerably from the stream bottom through increasing heights and appeared negligible above 2 m.

Samples were taken in November 1982, August 1983, and September 1983 in the Ogeechee River and on 9–10 September 1983 in Black Creek. Twenty-one transects were measured across each stream, which encompassed a distance of 3 km in the Ogeechee and 1 km in Black Creek, in areas where we have sampled benthic and snag populations of invertebrates. Whereas representative sampling was conducted, completely random samples were impossible. First, underwater stems were measured by snorkeling, and the combination of reduced vision and current limited underwater sampling to <2 m depths, and second, snorkeling was too hazardous when attempting to measure submerged stems of some of the extremely large fallen trees.

To assess the distribution of wood across an "average" transect in the Ogeechee River, the percentage of wood volume was determined within each 10% increment of stream width for each of the 21 transects at each of the three heights. The mean percentage of wood within each 10% increment for each height was calculated, and the mean values were plotted for this "average" transect.

A major objective in estimating wood surface area per square metre of stream bottom is to convert invertebrate densities per square metre of wood surface to densities per square metre of stream bottom. Since the amount of wood inundated changes continuously with the rising and falling hydrograph, secondary production estimates, based on invertebrate densities on snags, require a reasonable estimate of wood habitat availability at different water levels. Mean values for wood surface area at the three transect heights were used to develop predictive equations of surface area for a given river height and to estimate temporal patterns of wood habitat availability. Cumulative wood surface area at water level (submerged) and 1 and 2 m above the water was plotted against stream height (at United States Gelogical Survey gaging station). Weekly mean stage heights for the Ogeechee River and Black Creek (United States Geological Survey, unpubl. data) were used in these regression equations to obtain weekly estimates of submerged snag surface area per square metre of channel bottom over a 92-wk period.

On 14 December 1981, 19 snag samples were collected from the Ogeechee River. Organisms were removed from each snag and the wood surface area of each snag was estimated (see Benke et al. 1984 for details of procedure). After identification and enumeration of aquatic insects, densities of all taxa were converted to numbers and biomass per square metre of snag surface. Mean standing stock values were derived for the major functional feeding groups (modified after Cummins and Klug 1979).

Specific gravity measurements were required to convert our wood volume estimates to mass per square metre of channel bottom. A series of wood samples (n = 50) ranging from small twigs (4 mm in diameter) to large logs (>500 cm in diameter) were sampled to obtain specific gravity estimates. Dimensions of wood <3 cm in diameter were measured with vernier calipers to the nearest 0.1 mm to obtain volume. Larger limbs and tree trunks were cored with an increment borer (5.5 mm in diameter) and length (40–150 mm) of each core was measured with calipers. Each sample was oven-dried (50°C) for 5 d, desiccated for 2 d over $CaSO_4$, and weighed. Samples were then ashed at 500°C for 8 h and reweighed to obtain ash-free dry mass (AFDM). This procedure is intended as a rough estimate of wood mass in the streams based on the product of volume estimates, derived by line intersect, and specific gravity (using AFDM).

Results

Wood Surface Area and Volume

In the Ogeechee River, most wood (surface area and volume) is submerged, with each succeeding height being significantly less ($P < 0.05$) than that below it (Table 1). Wood surface area at the 0–1 m height is 58% of that found below the surface. At the 1–2 m height, it declines to 16% of that below the surface. The decline in wood volume is even sharper: 40% (0–1 m) and 7% (1–2 m).

In Black Creek, there is little difference between amount of submerged wood and that at the 0–1 m height (Table 1). Wood declines sharply at the 1–2 m height to 7% of the submerged surface area and 5% of the submerged volume. At low water,

TABLE 1. Wood surface area, volume, and mean diameters (±95% CI) in the Ogeechee River and Black Creek for submerged wood and wood 0–1 and 1–2 m above the surface of each stream. Based on 21 line intersect transects for each stream.

Item	Ogeechee River				Black Creek			
	Submerged	0–1 m above surface	1–2 m above surface	Total	Submerged	0–1 m above surface	1–2 m above surface	Total
Surface area of wood (m^2)/m^2 of stream bottom	0.249 (±0.078) [a]	0.145 (±0.045) [b]	0.0398 (±0.0146)	0.433	0.380 (±0.103) [b]	0.162 (±0.057) [b]	0.026 (±0.011)	0.568
Volume of wood (m^3)/m^2 of stream bottom	0.0101 (±0.0042) [b]	0.0040 (±0.0019) [b]	0.0007 (±0.0004)	0.0148	0.0110 (±0.0049) [c]	0.0056 (±0.0037) [b]	0.00003 (±0.0002)	0.0168
Surface area of wood (m^2)/linear m of stream	7.17 (±1.99) [a]	4.63 (±1.65) [b]	1.35 (±0.52)	13.16	3.76 (±0.98) [c]	3.26 (±1.06) [b]	0.530 (±0.230)	7.55
Volume of wood (m^3)/linear m of stream	0.328 (±0.126) [b]	0.131 (±0.061) [b]	0.027 (±0.009)	0.485	0.113 (±0.054) [c]	0.108 (±0.065) [b]	0.005 (±0.004)	0.227
$\bar{X}$ diam (cm)	3.53 (±0.78) [b]	2.01 (±0.62) [c]	1.26 (±0.70)		2.83 (±0.73) [c]	1.37 (±0.82) [c]	1.36 (±0.92)	

[a]95% CI, not significantly different among adjacent values; adjacent values significantly different based on paired t-test for each transect, i.e. submerged vs. 0–1 m above, etc.
[b]95% CI, significantly different among adjacent values.
[c]Paired t-test not significantly different among adjacent values.

when our measurements were taken, the stream width (i.e. wetted width) is only about half the total channel width, as large areas of sand bar are exposed (Fig. 1). At this time, the actual amount of wood surface per square metre of wetted *stream* bottom is 0.380 m^2, rather than 0.191 m^2/m^2 of *channel* bottom (as shown in Table 1). Thus, the amount of wood surface (0.380 m^2) per square metre of *stream* bottom at low water (when stream area is one-half of channel area) is virtually the same as the amount of wood surface (0.379 m^2) per square metre of *stream* bottom at bankfull discharge (when stream area equals channel area) (see total surface area in Table 1). Relatively little sand bar is exposed in the Ogeechee at low water, so the area of wetted stream surface is roughly the same as the area of channel bottom (bank-to-bank).

Total wood surface areas (0.43 m^2/m^2 for Ogeechee and 0.38 m^2/m^2 for Black Creek) (all heights) in each stream are quite high, and are not significantly different. Similarly, total wood volumes at bankfull discharge (0.148 m^3/m^2 for Ogeechee and 0.115 m^3/m^2 for Black Creek) are not significantly different between the streams. When either surface area or volume of wood is expressed per linear metre of stream, the Ogeechee values are about twice those of Black Creek, since the Ogeechee channel is about 50% wider (Table 1). These values are appropriate for channel wood; however, as the river rises above the 2-m height, water begins to invade the flood plain, which greatly increases total wood surface area per metre of stream length.

Mean stem diameter generally decreases from submerged to above-surface heights (Table 1). The diameters are strongly skewed toward smaller sizes by the great abundance of small twigs and branches compared with logs. The decrease in stem diameters is consistent with a general increase in the surface area to volume ratios (square metres per cubic metre), which are 24.7, 24.4, and 53.4 for wood at three elevations in the Ogeechee and 34.6, 28.9, and 98.4 for wood in Black Creek.

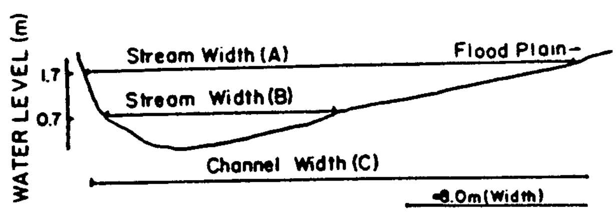

FIG. 1. Schematic illustration of stream width at different water levels compared with channel width for Black Creek. At low hydrograph (stage height = 0.7 m), when wood measurements were made (September 1983), stream width (B) was approximately one-half that of channel width (C). At a stage height of 1.7 m, stream width (A) approximates that of channel width (C).

Although mean stem diameters are strongly skewed toward the smaller stems, larger stems compose the majority of both wood surface area and volume (Table 2). Stems >10 cm in diameter composed over 92% of the total wood volume and 46% of the surface area in the Ogeechee and 74% of the total volume and 35% of the surface area in Black Creek.

Distribution of Wood

Wood distribution within each height (Fig. 2, bottom) can be compared with the depth profile (Fig. 2, top), which indicates the orientation of the wood towards the erosional bank (left side of Fig. 2). One should keep in mind that these are percentages *within* a height, and that absolute volumes between the three heights varied considerably (submerged > 0–1 m > 1–2 m) (Table 1).

All wood distribution is skewed toward the erosional bank; however, the distribution of submerged wood is less strongly skewed than above-surface wood (Fig. 2). Woody material in midstream consists primarily of large tree trunks (some >500 cm in diameter) that have lost most roots and limbs; thus, there is little woody material above the surface in midstream.

Table 2. Proportion (%) of total wood surface area and volume contributed by various stem diameter size classes in the Ogeechee River and Black Creek. All channel wood (wetted, 0–1, and 1–2 m above surface) is included.

	Size class (diameter in cm)			
	<1.0	1.0–5.0	5.1–10	>10
Ogeechee River				
% of surface area	8.14	23.77	21.68	46.4
% of wood volume	0.19	1.85	5.15	92.81
Black Creek				
% of surface area	20.99	26.92	17.07	35.02
% of wood volume	0.90	13.11	11.38	74.55

Some of the trunks are >30 m in length and partially buried in the stream bed, which suggests that the total volume of wood in these streams may be greatly underestimated, as buried wood was not measured.

Wood along the erosional bank generally consists of trunks, roots, branches, and twigs of fallen dead trees both above and below the water surface. However, about 25–35% of the above-surface wood consists of live, leaning trees and shrubs that become inundated at higher water. The increase in the 0–1 cm category between 6.7 and 10 m from the bank is attributed primarily to the tops of trees that have fallen into the stream along the erosional bank.

Wood along the depositional bank (right side of Fig. 2) consists primarily of live and dead willows (*Salix* spp.), which tend to grow horizontally from the shore. *Salix* forms valuable substrate for many aquatic insects such as black flies (Simuliidae), chironomids, and net-spinning caddisflies (Hydropsychidae) during periods of high water. Willows also serve as enhanced, although limited, sites for primary production with macrophytes such as *Micranthemum* sp., mosses (*Brachelyma subulatum*), liverworts (*Porella pinnata*), and algae during high water (E. L. Dunn, Georgia Institute of Technology, pers. comm.).

Wood Specific Gravity

Wood (twigs and logs) samples in the Ogeechee and Black Creek had a specific gravity of 0.408 ± 0.028 ($\bar{X}$ ± 95% CI, n = 50). Mean percent ash for wood samples was 1.85 ± 0.38%. Despite their external appearance of advanced stages of decay, logs >10 cm in diameter showed little evidence of any internal decomposition 0.5–1 cm below the surface. Some of these logs were embedded in the stream bed and overlaid with other logs, which suggests they may have been in these streams for many decades. Logs >10 cm in diameter had significantly higher specific gravity ($\bar{X}$ = 0.444 ± 0.028) than limbs and twigs <10 cm in diameter ($\bar{X}$ = 0.379 ± 0.044). The estimated AFDM of wood, based on the product of volume estimates in Table 1 and the specific gravity values of 0.444 (>10 cm in diameter) and 0.379 (<10 cm in diameter), is shown in Table 3. The total wood mass in the Ogeechee is about 6.46 kg AFDM/m^2 of channel bottom vs. 4.98 in Black Creek.

Wood Substrate Surface Area and Discharge

Cumulative wood surface area at water level (submerged) and 1 and 2 m above the water plotted against stream gage height was used to develop predictive equations for estimating wood habitat availability. For the Ogeechee River and Black Creek the curves of best fit were power regressions. For the Ogeechee:

(5) $S_b = 0.368H^{0.280}$ $\quad (r^2 = 0.33, n = 63)$

(6) $S_l = 11.122H^{0.239}$ $\quad (r^2 = 0.38, n = 63)$

and for Black Creek:

(7) $S_b = 0.210H^{0.748}$ $\quad (r^2 = 0.46, n = 63)$

(8) $S_l = 4.094H^{0.663}$ $\quad (r^2 = 0.43, n = 63)$

where S_b = square metres of wood surface area per square metre of stream bottom, S_l = square metres of wood surface area per linear metre of stream, and H = stream height (metres). The relatively low r^2 reflects the high variability of wood estimates among transects.

Weekly estimates of submerged snag surface area were made from stream height using equations 5 and 7. Snag surface area follows rather distinct seasonal cycles, increasing during late fall and early winter as water levels rise and decreasing during late spring and summer with falling water levels. Although total discharge varies more than an order of magnitude in the Ogeechee (5–280 m^3/s) and about 3 orders of magnitude in Black Creek (0.05–45 m^3/s) over this time period, in-channel snag surface area varies only threefold (0.15–0.51 m^2/m^2 of channel bottom in the Ogeechee; 0.16–0.48 m^2/m^2 in Black Creek). However, snag surface area is subject to more abrupt changes in Black Creek (Fig. 3).

Equations 5–8 can be utilized to convert animal numbers and biomass into more meaningful ecosystem units. On 19 December 1981, river height was 0.409 m. This value was used in equations 5 and 6 to yield S_b = 0.287 m^2 of wood surface/m^2 of stream channel and S_l = 8.98 m^2 of wood surface area/linear m of stream. The product of these values and the density and biomass of organisms per square metre of snag surface are shown in the last four columns of Table 4. Biomass and density of snag dwelling organisms are still fairly high even when expressed per square metre of channel bottom. The value of 1.88 g dry mass/m^2 of channel bottom for snag animals is considerably higher than all benthic (i.e. non-snag) insects and oligochaetes on this same date (<1 g dry mass/m^2, unpubl. data). When benthic molluscs (1.8 g dry mass/m^2, unpubl. data) are included, total benthic biomass slightly surpasses that of snags.

Discussion

In low-gradient, meandering streams, bank failure along the erosional bank is believed to deliver most woody material to the stream bed (Sigafoos 1964; Keller and Swanson 1979). In the Ogeechee, about 45% of submerged wood is between 3.3 and 10 m (or 11–30% of stream width) from the erosional bank. As these deeply cut banks erode, tree trunks and limbs form rather dense partial debris dams at angles to the main flow. These debris dams are partially stabilized by large roots of fallen trees that remain anchored in the bank. The fallen trees serve to retain other large woody material that may be transported from upstream and the adjacent flood plain forest.

The estimates of wood biomass in our fourth- and sixth-order streams are similar to several first- and second-order streams in other regions, but lower than those from the Pacific Northwest and California redwood forests (Table 5). We should emphasize that Black Creek and the Ogeechee are fourth- and sixth-order streams. We also regard our estimates as low, particularly since

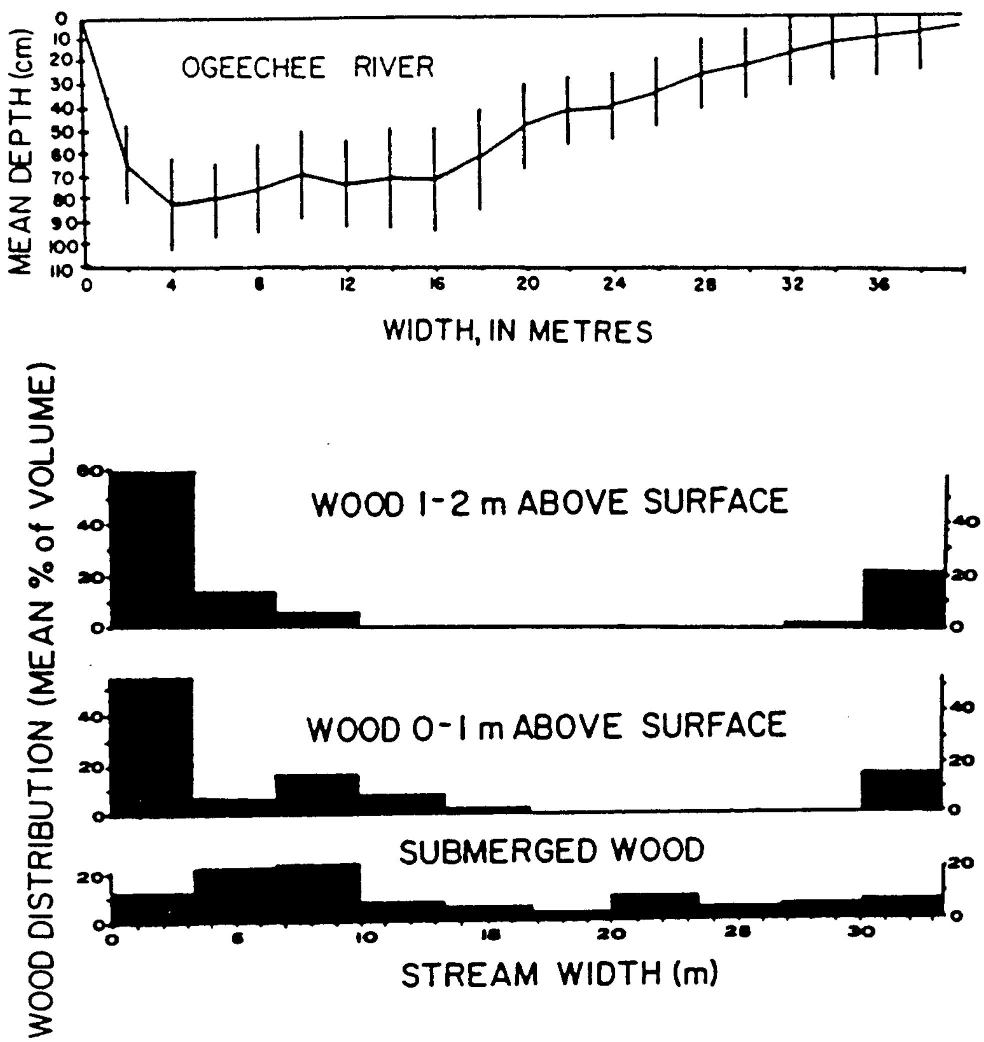

FIG. 2. Top, mean depth profile of the Ogeechee River, with erosional bank at 0 regardless of bank orientation, i.e. east or west bank. The vertical lines represent the 95% CI for depth (cm) at 2-m intervals from the erosional bank during low hydrograph in late August 1983. The apparent width of this depth profile is equal to the width of the longest transect, since each mean depth is based on a fixed distance (up to 40 m) from the erosional bank. Bottom, mean percentage of distribution of wood volume across an "average" transect with a mean channel width of 33 m for wood that is submerged, 0–1 m above surface, and 1–2 m above surface during low hydrograph in late August 1983. These data are based on the percentage *within* each 10% increment of width for each height. Note that wood distribution is skewed toward the erosional bank (see text).

we could not include the very large logs that were embedded in the substrate.

Relationship with Flood Plain

These estimates of snag surface area are only for in-channel wood, and these are valid as systems-level measurements only while the river remains within its banks. At stage height of 2 m (indicated by f.s.O.R. in Fig. 3), total Ogeechee discharge is about 70 m^3/s, with about 18% of discharge flowing through low-lying portions of the flood plain swamp forest. Snag substrate estimates do not consider the unmeasured wood surfaces that become inundated in the swamp. Between the 2- and 3-m heights (f.s., Fig. 3), the river inundates substantial portions of the swamp surface, and these in-channel estimates become increasingly conservative as measures of available habitat surfaces. At the 3-m height, total discharge is 220 m^3/s, with nearly half of total discharge flowing through the swamps, and the amount of swamp surface inundated is more than 10 times greater than the river surface (based on digitized area from infrared satellite photograph, 27 February 1981). In Black Creek on this date, greater than 5 times more swamp surface was inundated than the channel surface area.

Preliminary estimates of woody litter (twigs and logs) on the adjacent flood plain forest floor indicate 1.03–2.3 kg AFDM/m^2 of wood on the Ogeechee flood plain and approximately 0.6 kg/m^2 on the Black Creek flood plain (T. F. Cuffney, University of Georgia, pers. comm.). These latter values are on the lower end of the 0.2–21.8 kg/m^2 range listed by Triska and Cromack (1980) for nine north temperate forests. The estimate of wood in the Ogeechee channel (6.46 kg/m^2) is about 2.8–6.3 times higher than that of the adjacent flood plain forest floor whereas channel wood in Black Creek (4.98 kg/m^2) is 8.3 times greater than wood on its flood plain. This difference may be due in part to movement of wood from the extensive flood plain to the stream during flood stage. Evidence for this is seen on the

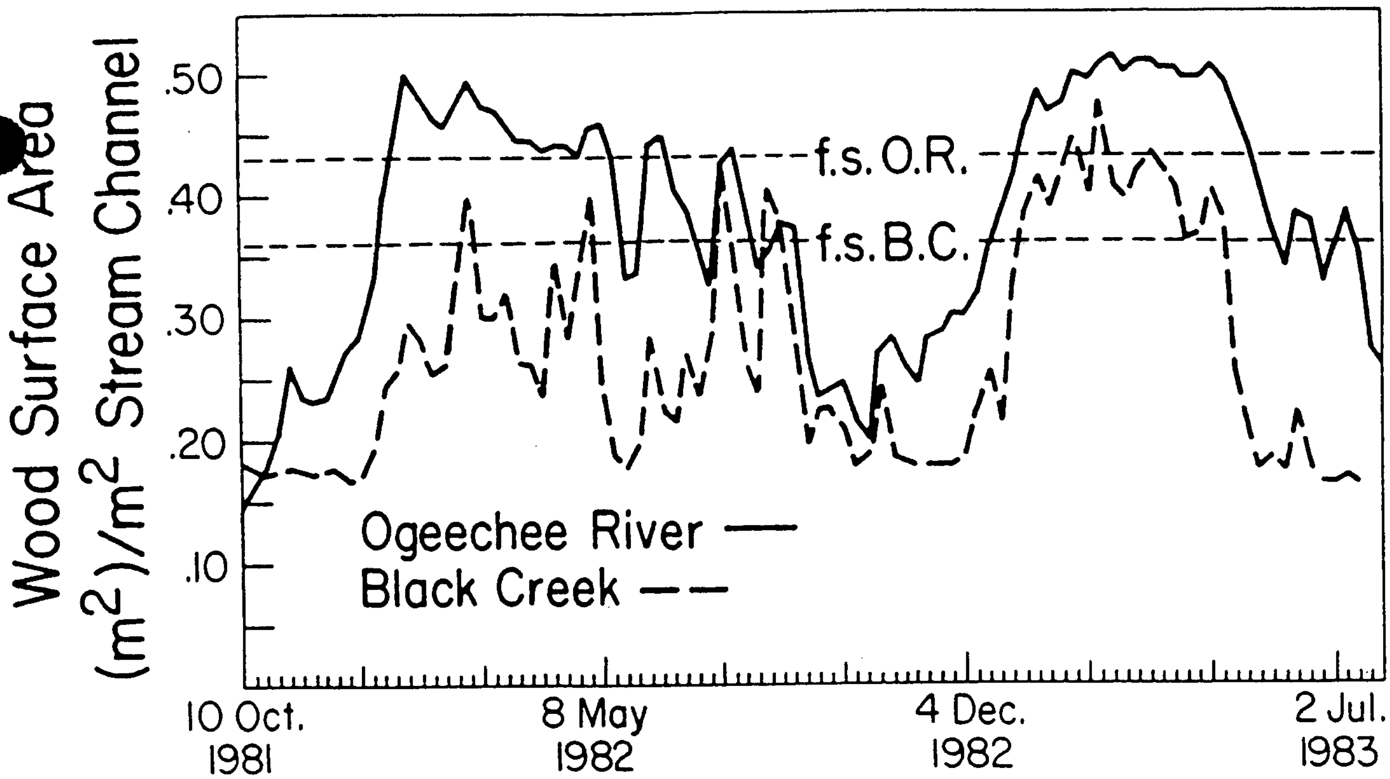

FIG. 3. Weekly means for wood substrate surface area per unit channel bottom for the Ogeechee River (O.R.) and Black Creek (B.C.) during the period encompassing 10 October 1981 through 7 July 1983. These estimates are based on weekly means of stage heights (United States Geological Survey, unpubl. data) regressed with cumulative wood surface area at water level and 1 and 2 m above the surface. These estimates are conservative at stage heights above the level marked flood stage (f.s.) when the streams inundate vast areas of flood plain forest.

TABLE 3. Estimated ash-free dry mass of wood (kg AFDM/m^2 of channel bottom ± 95% CI) in the Ogeechee River and Black Creek for three transect heights in each stream.

	Transect heights			
Stream	Submerged	0–1 m above surface	1–2 m above surface	Total
Ogeechee River	4.407 (±1.83)	1.75 (±0.83)	0.30 (±0.17)	6.46
Black Creek	2.41 (±1.05)	2.45 (±1.60)	0.12 (±0.10)	4.98

flood plain where widely scattered debris masses can be observed, while much of the surrounding forest floor is remarkably clean following floods. Woody litter fall may also be higher along the erosional bank of these streams than in the adjacent flood plain forests. Furthermore, the rate of wood decomposition in water is considerably slower than that on land (e.g. Triska and Cromack 1980; Aumen et al. 1983). Most wood volume in both the Ogeechee and Black Creek is in larger (>10 cm in diameter) stem sizes (Table 2). Since wood decomposition in streams occurs primarily from the periphery toward the interior (Triska and Cromack 1980; Aumen et al. 1983), larger diameter wood decomposes much slower than smaller stems. Hence, the majority of wood volume in the Ogeechee and Black Creek would be expected to have very slow decomposition rates. Thus, entrainment and subsequent retention, higher woody litter input rates, and slower decomposition rates may contribute to higher quantities of wood in these stream channels than on their adjacent flood plains.

Wood distribution in these low-gradient, flood plain river systems is in marked contrast with that of similar stream orders in the Pacific Northwest. In the McKenzie River, Oregon, there is little wood in the river channel (Keller and Swanson 1979; Triska and Cromack 1980; Triska et al. 1982). The McKenzie has a mean annual discharge of 75.3 m^3/s (Naiman and Sedell 1979b), which is only slightly higher than the Ogeechee (67.7 m^3/s). However, calculated as unit stream power, a measure of a stream's ability to perform work (Leopold et al. 1964), where unit power = density × discharge (cubic metres per second) × % slope/width (metres), indicates that the McKenzie has about 35 times more unit stream power than the Ogeechee at mean discharge. This difference is primarily attributable to the much greater slope of the McKenzie (0.6%, Naiman and Sedell 1979b) vs. only 0.02% for the Ogeechee. Unit stream power differences between these rivers increases at high discharge because the Ogeechee widens considerably (flood plain flow) and mean stream velocity declines. Thus, the McKenzie has more capacity to move large materials than the Ogeechee.

Historical Perspective

Early in Georgia history, before the advent of railways, rivers were the main arteries of transportation. Some of the problems of pioneers in navigation of these Coastal Plain rivers are indicated in Fig. 2. Most wood is located along the main thalweg of the river. In 1801, Act 26 of the Georgia Legislature allowed the formation of a company to improve navigation on the Ogeechee River for a distance of about 230 river km. Similar

TABLE 4. Densities and dry mass (DM) of aquatic insects on the snag habitat of the Ogeechee River on 14 December 1981 and their equivalent densities and mass per m^2 of channel bottom and per linear m of stream.

Functional feeding group	Snag surface		Channel bottom		Linear m of stream	
	No./m^2	mg DM/m^2	No./m^2	mg DM/m^2	Thousands/m	g DM/m
Macrofiltering collectors (e.g. *Hydropsyche*)	3 337	4222	958	1212	30.0	37.9
Microfiltering collectors (e.g. *Simulium*)	15 880	827	4 558	237	143.0	7.4
Shredders (e.g. *Pteronarcys*)	55	92	16	26	0.49	0.83
Gathering collectors (e.g. *Stenonema*)	13 332	395	3 826	113	120.0	3.5
Wood feeders (e.g. *Stenelmis*)	1 916	415	550	119	17.2	3.7
Predators (e.g. *Perlesta*)	6 218	611	1 785	175	55.8	5.5
Total	40 738	6562	11 693	1882	366.5	58.8

TABLE 5. Estimates of channel wood mass in various streams in North America.

Location	Stream order	Forest type	Wood (kg/m^2)
California[a]	1st–2nd	Redwood[e]	45–80
Alaska[b]	1st–2nd	Sitka spruce[f] – hemlock[g] (clearcuts)	15.7–61.8
Oregon[a]	1st–2nd	Old growth Douglas fir[h] – hemlock[g]	25–40
Oregon[c]	1st	Old growth Douglas fir[h]	23.6
Oregon[a]	1st–2nd	Young growth Douglas fir[h] – hemlock[g]	20–25
North Carolina[d]	1st–2nd	Old growth mixed hardwood – hemlock[i]	21–24
Oregon[c]	3rd	Douglas fir[h]	14
Alaska[b]	1st–2nd	Old growth Sitka spruce[f] – hemlock[g]	3.2–12.7
Tennessee[a]	1st–2nd	Mixed hardwoods	13
North Carolina[d]	1st–2nd	50- to 60-yr-old mixed hardwoods	10.3
Idaho[a]	1st–2nd	Old growth spruce[j] – lodgepole pine[k]	7.0
Georgia	6th	Ogeechee (this study)	6.5
Oregon[c]	4th	Douglas fir[h] – red alder[l]	5.7
Georgia	4th	Black Creek (this study)	5.0
Michigan[a]	1st–2nd	Young growth mixed hardwoods	4–8
New Hampshire[a]	1st–2nd	Old growth spruce[m] – fir[n]	4
Oregon[d]	7th	Douglas fir[h] – red alder[l] (McKenzie River)	0.75
North Carolina[d]	1st–2nd	15-yr clearcut, all slash removed, burned	<0.5

[a]Triska and Cromack (1980); includes wood > 10 cm; no methods given; dry mass (?).
[b]Swanson et al. (1984); includes all wood diameters using combinations of line intersect and scaling techniques; based on several streams in both clearcut and uncut forests; dry mass.
[c]Naiman and Sedell (1979a); includes all wood; mapping (>10 cm) and handpicking; AFDM (based on 10% ash content).
[d]J. B. Wallace and A. Huryn, unpubl. data; includes all channel wood, using line intersect technique as presented in this study; AFDM.
[e]*Sequoia sempervirens.*
[f]*Picea sitchensis.*
[g]*Tsuga heterophylla.*
[h]*Pseudotsuga taxifolia.*
[i]*Tsuga canadensis.*
[j]*Picea englemanni.*
[k]*Pinus contorta.*
[l]*Alnus rubra.*
[m]*Picea* spp.
[n]*Abies balsamea.*

acts were passed the same year for the Savannah, Altamaha, and Oconee rivers. Specifically, these acts called for the removal of as many as possible obstructions (primarily wood) to the navigation of these rivers. Although we have not been able to document the actual amount of wood removed from the Ogeechee, the process was apparently successful (Clayton 1812). By the 1850s many river projects were abandoned in Georgia, especially on smaller rivers such as the Ogeechee where steamboats were impractical, and transportation turned to railways (Coleman et al. 1977). However, the United States Army Corps of Engineers continued to remove snags with snagboats from the Altamaha, Savannah, and lower Satilla rivers until the 1950s (United States Army Corps of Engineers 1953). Thus, snag removal operations have been conducted intermittently in Georgia Coastal Plain rivers over a period of 150 yr. Similar snag removal operations were conducted by the Corps from many rivers throughout the United States during the late 1800s and early 1900s (Sedell et al. 1982).

Snag surface area estimates in both the Ogeechee River and Black Creek (Table 1) are much higher than that made by Benke et al. (1984) for the Satilla River (0.05–0.07 m^2/m^2 of channel bottom) in southeastern Georgia. Two factors may have contributed to some underestimation of snags in the Satilla. First, in the Satilla, only snags along the shoreline were considered. Second, the method used by Benke et al. (1984) differed from the line intersect used here in that horizontal rather than vertical transects (planes) were used at three heights, and submerged wood was not actually measured and assumed to have the same abundance as the mean of other heights. Notwithstanding this possible underestimation, the Satilla River indeed appears to have less woody material than the Ogeechee or Black Creek. The lower wood estimates in the Satilla may be largely attributable to the extensive snag removal operations as recently as the 1940s. During this period about 15 000 snags including trees and stumps were removed from the lower 260 km of the Satilla (J. R. Sedell, U.S. Forest Service, Corvallis, OR, pers. comm.). To our knowledge, there were no other major differences in riparian zone management practices of the two rivers that would account for lower estimates of channel wood in the Satilla.

Potential Impact of Snagging on Coastal Plain Streams

We can assume that man began having a very significant impact on Georgia rivers through snagging efforts initiated by the early 1800s at latest. We predict several potential impacts that may have resulted from early snagging efforts.

First, there was an immediate negative impact on invertebrate diversity and secondary production because of habitat removal. Benke et al. (1984) found that although the snag habitat represented only 6% of the Satilla habitat (compared with muddy backwaters and sand), snags accounted for the greatest diversity of species, and for the river as a whole, over half the invertebrate biomass and 15–16% of secondary production. Preliminary data from the Ogeechee (Table 4) indicate that invertebrate densities and biomass on snags are very similar to those in the Satilla (3–6 g dry mass/m^2 of snag surface). Secondary production of invertebrates on snag substrates in the Satilla River was at least 50 g dry mass·m^{-2} snag surface area·yr^{-1} (Benke et al. 1984). Cudney and Wallace (1980) obtained similar estimates of secondary production on snags in the larger Savannah River. Assuming that Ogeechee snags have somewhat similar levels of secondary production as above (e.g. 50 + g dry mass·m^{-2} snag surface area·yr^{-1}) with more snag surfaces the Ogeechee may have 5 times as much snag invertebrate production as the Satilla. Several species of game fishes obtain at least 60% of their food from the snag habitat in the Satilla (Benke et al. 1979; Benke et al., unpubl. data). A snagging operation that removed only 50% of the wood would have a very adverse influence on invertebrate production and the fishes that depend on them for food. Snagging would also remove fish habitat and cover (e.g. Marzolf 1978; Sedell et al. 1982).

Second, the major invertebrate functional group inhabiting snags are filtering collectors that exploit the suspended organic particles made available to them by the current (Cudney and Wallace 1980; Benke et al. 1984). The loss of significant filtering-collector populations from a given reach of stream, combined with losses of snag inhabiting algae and macrophytes, may increase the spiralling length (e.g. Webster 1975; Wallace et al. 1977; Newbold et al. 1982) of nutrients and energy. This would reduce the ability of a given stream segment to process and conserve nutrient and energy inputs.

Third, woody debris is the major item contributing to high roughness coefficients, Manning's n, in streams traversing sandy or clay soils (Chow 1959). In the Manning formula, $V = (1.0/n)R^{2/3}S^{1/2}$, where V = mean velocity (metres per second), R = hydraulic radius (metres), S is the slope of the energy line, and n = Manning's roughness coefficient. Values of n approach 0.150 with the presence of roots, trees, and large logs (Chow 1959, p. 123). This n value exceeds that of fairly clean, regular bottom rivers by over 4 times (Chow 1959). Thus, snags may significantly reduce mean stream velocities and increase settling rates of entrained particles; conversely, snag removal would increase velocity, leading to accelerated transport and thereby further reduce the ability of flora and fauna to process nutrients and organic matter within a stream segment (Swanson et al. 1976). Snags also act as partial debris dams. The increased retention of organic matter may decrease community metabolism, (P/R) ratios, and represent an important factor contributing to the usual heterotrophic condition ($P/R < 1$) of blackwater rivers. Snag removal may also alter river – flood plain interactions via lower roughness, increasing the velocity of flow. This could reduce the frequency and duration of flood plain inundation, and drastically alter nutrient and organic matter pathways.

In summary, the input and retention of woody material, primarily the result of physical processes, provides large, relatively stable substrate for invertebrate colonization in an environment that would otherwise be unsuitable for colonization by many species of animals. The physical environment appears to have influenced the evolution of the biota that exploits these snag substrates, primarily filtering collectors (Cudney and Wallace 1980; Benke et al. 1984), which depend on the entrained particles for their nutrition. As pointed out by Sedell et al. (1982), many state and local agencies emphasize the removal of stream obstructions as a basis for stream and habitat improvement programs. For streams in the southeastern Coastal Plain, the benefits of such operations are, at best, extremely dubious in that snagging operations could seriously reduce both invertebrate and fish production. Similar situations may exist in midwestern streams (based on invertebrate densities reported for woody substrates, Nilson and Larimore 1973) and in the vast lowland streams of the Amazon Basin (e.g. Fittkau et al. 1975; Fittkau 1982; Sioli 1982). Although there are exceptions (e.g. Shields and Nunnally 1984), the best management for such streams and their adjacent flood plains is no "management" other than protection of adjacent flood plains. The biota obviously evolved in response to physical processes long before man interfered with these physical–biological linkages.

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References

ANDERSON, N. H., AND J. R. SEDELL. 1979. Detritus processing by macroinvertebrates in stream ecosystems. Annu. Rev. Entomol. 24: 351–357.

ANDERSON, N. H., J. R. SEDELL, L. M. ROBERTS, AND F. J. TRISKA. 1978. Role of aquatic invertebrates in processing wood debris of coniferous forest streams. Am. Midl. Nat. 100: 64–82.

AUMEN, N. G., P. J. BOTTOMLEY, G. M. WARD, AND S. V. GREGORY. 1983. Microbial decomposition of wood in streams: distribution of microflora factors affecting [^{14}C]lignocellulose mineralization. Appl. Environ. Microbiol. 46: 1409–1416.

BENKE, A. C., D. M. GILLESPIE, F. K. PARRISH, T. C. VAN ARSDALL, JR., R. J. HUNTER, AND R. L. HENRY, III. 1979. Biological basis for assessing impacts of channel modification: invertebrate production, drift, and fish feeding in a southeastern blackwater river. Environmental Resources Center Publication No. ERC 06-79, Georgia Institute of Technology, Atlanta, GA. 187 p.

BENKE, A. C., T. C. VAN ARSDALL, JR., D. M. GILLESPIE, AND F. K. PARRISH. 1984. Invertebrate productivity in a subtropical blackwater river: the importance of habitat and life history. Ecol. Monogr. 54: 25–63.

BILBY, R. E. 1981. Role of organic debris dams in regulating export of dissolved and particulate matter from a forested watershed. Ecology 62: 1234–1243.

BILBY, R. E., AND G. E. LIKENS. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology 61: 1107–1113.

CHOW, V. T. 1959. Open channel hydraulics. McGraw-Hill, New York, NY. 680 p.

CLAYTON, A. S. 1812. A compilation of the laws of the state of Georgia since the political year 1800 to the year 1810. Adams and Duyckince, Augusta, GA. 708 p.

COLEMAN, K., N. V. BARTLEY, W. F. HOLMES, F. N. BONEY, AND P. SPALDING. 1979. A history of Georgia. University of Georgia Press, Athens, GA. 455 p.

CUDNEY, M. D., AND J. B. WALLACE. 1980. Life cycles, microdistribution, and production dynamics of six species of net-spinning caddisflies in a large southeastern (U.S.A.) river. Holarct. Ecol. 3: 169–182.

CUMMINS, K. W. 1974. The structure and function of stream ecosystems. BioScience 24: 631–641.

CUMMINS, K. W., AND M. J. KLUG. 1979. Feeding ecology of stream invertebrates. Annu. Rev. Ecol. Syst. 10: 147–172.

DE VRIES, D. G. 1974. Multi-stage line intersect sampling. For. Sci. 20: 129–133.

DUDLEY, T., AND N. H. ANDERSON. 1982. A survey of invertebrates associated with wood debris in aquatic habitats. Melanderia 39: 1–21.

FITTKAU, E. J. 1982. Struktur, Funktion und Diversitat zentralamazonischer Okosysteme. Arch. Hydrobiol. 95: 29–45.

FITTKAU, E. J., U. IRMLER, W. J. JUNK, F. REISS, AND G. W. SCHMIDT. 1975. Productivity, biomass, and population dynamics in Amazonian water bodies, p. 289–311. *In* F. B. Golley and E. Medina [ed.] Ecological studies 11. Tropical ecological systems. Trends in terrestrial and aquatic research. Springer-Verlag, New York, NY. 398 p.

HYNES, H. B. N. 1975. The stream and its valley. Verh. Int. Ver. Limnol. 19: 1–15.

KELLER, E. A., AND F. J. SWANSON. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surf. Proc. 4: 361–380.

LEOPOLD, L. B., M. G. WOLMAN, AND J. P. MILLER. 1964. Fluvial processes in geomorphology. W. H. Freeman, San Francisco, CA. 522 p.

MARZOLF, G. R. 1978. The potential effects of clearing and snagging on stream ecosystems. United States Department of Interior, Fish and Wildlife Service/OBS-78-14, Washington, DC. 31 p.

MELILLO, J. M., R. J. NAIMAN, J. D. ABER, AND K. N. ESHLEMAN. 1983. The influence of substrate quality and stream size on wood decomposition dynamics. Oecologia (Berl.) 58: 281–285.

MINSHALL, G. W., R. C. PETERSEN, K. W. CUMMINS, T. L. BOTT, J. R. SEDELL, C. E. CUSHING, AND R. L. VANNOTE. 1983. Interbiome comparison of stream ecosystem dynamics. Ecol. Monogr. 53: 1–25.

MOLLES, M. C. JR. 1982. The Trichoptera of streams associated with aspen and spruce-fir forests: long term community change. Ecology 63: 1–6.

NAIMAN, R. J., AND J. R. SEDELL. 1979a. Benthic organic matter as a function of stream order in Oregon. Arch. Hydrobiol. 87: 404–422.

1979b. Characterization of particulate organic matter transported by some Cascade Mountain streams. J. Fish. Res. Board Can. 36: 17–31.

NEWBOLD, J. D., R. V. ONEILL, J. W. ELWOOD, AND R. VAN WINKLE. 1982. Nutrient spiralling in streams: implications for nutrient limitation and invertebrate activity. Am. Nat. 120: 628–652.

NILSON, H. C., AND R. W. LARIMORE. 1973. Establishment of invertebrate communities on log substrates in the Kaskaskia River, Illinois. Ecology 54: 366–374.

PEREIRA, C. R. D., N. H. ANDERSON, AND T. DUDLEY. 1982. Gut content analysis of aquatic insects from wood substrates. Melanderia 39: 23–33.

ROUNICK, J. S., AND M. J. WINTERBOURN. 1983. Leaf processing in two contrasting beech forest streams: effects of physical and biotic factors on litter breakdown. Arch. Hydrobiol. 96: 448–474.

SEDELL, J. R., F. H. EVEREST, AND F. J. SWANSON. 1982. Fish habitat and streamside management: past and present, p. 244–255. Proc. Soc. Am. For. Annu. Meet. (September 27–30, 1981) Soc. Am. For., Bethesda, MD.

SHIELDS, F. D. JR., AND N. R. NUNNALLY. 1984. Environmental aspects of clearing and snagging. J. Environ. Engr. 110: 152–165.

SIGAFOOS, R. S. 1964. Botanical evidence of floods and flood plain deposition. U.S. Geol. Surv. Prof. Pap. 485A, Washington, DC. 35 p.

SIOLI, H. 1982. Tropische Flusse in ihren Beziehungen zur terrestrischen Umgebung und im Hinblick auf menschliche Eingriffe. Arch. Hydrobiol. 95: 463–485.

SWANSON, F. J., M. D. BRYANT, G. W. LIENKAEMPER, AND J. R. SEDELL. 1984. Organic debris in small streams, Prince of Wales Island, southeast Alaska. U.S. Dep. Agric. For. Ser. Gen. Tech. Rep. PNW-166: 12 p.

SWANSON, F. J., G. W. LIENKAEMPER, AND J. R. SEDELL. 1976. History, physical effects and management implications of large organic debris in western Oregon streams. U.S. Dep. Agric. For. Ser. Gen. Tech. Rep. PNW-56: 15 p.

TRISKA, F. J., AND K. CROMACK, JR. 1980. The role of wood debris in forests and streams, p. 171–190. *In* R. H. Waring [ed.] Forests: fresh perspectives from ecosystem analysis. Oregon State University Press, Corvallis, OR. 198 p.

TRISKA, F. J., J. R. SEDELL, AND S. V. GREGORY. 1982. Coniferous forest streams, p. 292–332. *In* R. L. Edmonds [ed.] Analysis of coniferous forest ecosystems in the western United States. Chap. 10. US/IBP Synthesis Ser. 14. Hutchinson and Ross Publishing Co., Stroudsburg, PA. 419 p.

UNITED STATES ARMY CORPS OF ENGINEERS. 1953. Water resources development by the Corps of Engineers in Georgia. January, 1953, Atlanta, GA. 14 p.

UNITED STATES GEOLOGICAL SURVEY. 1982. Water resources data for Georgia, water year 1981. Doraville, GA. 446 p.

VAN WAGNER, C. E. 1969. The line intersect method in forest fuel sampling. For. Sci. 14: 20–26.

VANNOTE, R. L., G. W. MINSHALL, K. W. CUMMINS, J. R. SEDELL, AND C. E. CUSHING. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37: 130–137.

WALLACE, J. B., D. H. ROSS, AND J. L. MEYER. 1982. Seston and dissolved organic carbon dynamics in a southern Appalachian stream. Ecology 63: 824–838.

WALLACE, J. B., J. R. WEBSTER, AND W. R. WOODALL. 1977. The role of filter feeders in flowing waters. Arch. Hydrobiol. 79: 506–532.

WARREN, W. G., AND P. F. OLSEN. 1964. A line intersect technique for assessing logging waste. For. Sci. 10: 267–276.

WEBSTER, J. R. 1975. Analysis of potassium and calcium dynamics in stream ecosystems on three southern Appalachian watersheds of contrasting vegetation. Doctoral dissertation, University of Georgia, Athens, GA. 232 p.

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THE FLATWOODS SALAMANDER: GENERAL BACKGROUND

Status:

The flatwoods salamander (*Ambystoma cingulatum*) is listed as threatened under the Endangered Species Act (ESA) of 1973 (as amended).[1] The primary threat to this species is loss of both its wetland and upland forested habitat.

Description:

The flatwoods salamander is medium-sized, reaching an adult length of 5 inches (13 centimeters). Body color ranges from silvery gray to black, with the back heavily mottled with a variable gray cross-band pattern. The underside is plain gray with faint creamy blotches. The head is small and equal to the neck in diameter.[2] Adults are most easily confused with the slimy salamander (*Plethodon grobmani*), small-mouth salamander (*Ambystoma texanum*), or Mabee's salamander (*Ambystoma mabeei*).

Larvae are long and slender, with broad heads, slim legs, and bushy gills. They have a distinct striped body pattern with wide longitudinal lines. The head has a distinctive dark brown stripe passing through the eye from the nostril to the gills. Other *Ambystoma* larvae with a similar appearance include Mabee's salamander and the mole salamander (*A. talpoideum*). Unlike Mabee's salamander, the lateral stripes of the flatwoods salamander are continuous. The mole salamander is distinguishable by its dark mid-ventral stripe and crossbands.[3]

Habitat and Occurrence:

The flatwoods salamander inhabits moist soil of longleaf pine (*Pinus palustris*) and slash pine (*P. elliottii*) flatwoods of the southeastern coastal plain in Florida, Georgia, and South Carolina. Not all flatwoods are appropriate habitat; the flatwoods salamander only occurs at sites with the seasonal ponds they require for breeding. These flatwoods are usually fire-maintained and rich in groundcover, providing abundant invertebrates as a food source. The flatwoods salamander lives underground in burrows for most of the year, except during the breeding season. Burrows may be enlarged crayfish burrows, or they may dig their own. Adults can be difficult to locate.

Populations have been documented from the Florida panhandle east to Jacksonville, and in southwest Georgia, and the coastal counties of Georgia and South Carolina. While historically occurring in Alabama, none have been observed since 1981. In Florida, thirty-six populations are currently known to exist. The Florida populations comprise 71% of the known populations of the flatwoods salamander throughout their range. Half of these populations are on public lands at Eglin Air Force Base and the Apalachicola National Forest. The Florida counties with documented recent breeding sites (after 1990) include: Baker, Calhoun, Franklin, Holmes, Jackson, Jefferson, Liberty, Okaloosa, Santa Rosa, Walton, and Washington counties. Additional counties with historical occurrence are Alachua, Bradford, Duval, and Marion counties.

Breeding Sites:

The breeding season extends from October to January. Adults surface and migrate to breeding sites during periods of rain and cool temperatures. Breeding sites are low-lying areas which form ephemeral ponds during the wet season. These ponds are small and shallow, with an open canopy, typically under 4

acres and less than 15 inches deep. Vegetation along the edge is dominated by sedges, rushes, wiregrasses, and panic grasses, with trees and shrubs growing both in and around the pond. Eggs may be laid singly or in clumps, and are attached to dry vegetation. As pond water levels rise with continued rain, the developing eggs become inundated and begin to hatch. The larval period lasts from 11 to 18 weeks. Larvae metamorphose into adults in March and April. Successful reproduction and larval development are highly dependent on rainfall and weather patterns.

Impacts of Listing on Federal Actions:

Activities on Federal lands which may impact the flatwoods salamander are actions that compact the soil and/or alter the hydrology of the wetland breeding sites by ditching or draining. Under Section 7 (a)(2) of the ESA, Federal agencies are required to evaluate their actions with respect to listed species.

Impacts of Listing on Private Lands:

Flatwoods salamanders are uncommon on private lands. Sites where they do occur are frequently managed for timber. When silviculture is managed to duplicate natural ecological processes, such as seasonal burning and selective harvest, it is compatible with the habitat needs of the flatwoods salamander. With planning, private landowners can manage their lands to avoid actions detrimental to the flatwoods salamander, considered "take" under Section 9 of the ESA. Habitat conservation plans can also be developed to allow the continuance of lawful activities while permitting limited incidental take as a result of those activities. Also, Safe Harbor plans can be developed to increase populations of the flatwoods salamander without precluding future land management options.

Detrimental Actions:

Some examples of actions that could negatively impact the flatwoods salamander include:

* destruction or alteration of wetlands used as breeding sites

* destruction or alteration of suitable habitat within a 450 m (1476 ft) radius of a known breeding pond

* unauthorized collecting, handling or harassing flatwoods salamanders

* possessing, selling, transporting, or shipping illegally taken flatwoods salamanders

* discharging or dumping toxic chemicals, silt, and other pollutants into habitats supporting the species

* use of pesticides or herbicides in a manner not in accordance with label restrictions

References Cited

1. U.S. Fish & Wildlife Service. April 1, 1999. Endangered and Threatened Wildlife and Plants; Final Rule to List the Flatwoods Salamander as a Threatened Species. Federal Register 62(241): 15691-15704.

2. Ashton, R.E., Jr. and P.S. Ashton. 1988. Handbook of Reptiles and Amphibians of Florida, Part Three, The Amphibians, Windward Publications, Incorporated.

3. Palis, J. G. 1997. Species Profile: Flatwoods Salamander (*Ambystoma cingulatum*) on Military Installations in the Southeastern United States, Technical Report SERDP-97-6. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

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RECOMMENDED TIMBER MANAGEMENT PRACTICES FOR THE FLATWOODS SALAMANDER[1]

Silviculture techniques which mirror the natural pine flatwoods ecosystem provide the most benefit to flatwoods salamander populations. Goals are to curtail activities during the breeding and dispersal season (October to April), avoid soil disruption and compaction, prevent hydrologic change, and maintain an open overstory and herbaceous ground cover. To achieve these goals, timber harvesting in pine flatwoods habitat within a 450 meter (1476 ft) radius buffer zone surrounding a known flatwoods salamander breeding pond should be conducted according to the following guidelines. Timber harvests using these guidelines would not likely adversely affect flatwoods salamanders.

1. For a primary zone of 164 m (538 ft) from the pond edge use selective harvest, harvest only during dry periods, and harvest at a minimum of 10-year intervals. Maintain a basal area of 4.2 to 4.7 m^2 per hectare (45-50 ft^2 per acre).

2. For a secondary zone from 164 to 450 m (538-1476 ft) from the pond edge: use a mix of clear-cutting and selective harvest, harvesting only during dry periods and at a minimum of 10-year intervals. Clear-cut up to 25 percent at any given time, while maintaining 75 percent of the pine flatwoods habitat. Basal area should be maintained at 4.2 to 4.7 m^2 per hectare (45-50 ft^2 per acre). The primary and secondary zones should not be separated by cleared or non-pine flatwoods habitat.

3. Skid trails and their effects should be minimized through the use of prescription planning. Skid trails should be carefully located so that the wetland hydrology is not altered. All log landings should be located outside the primary and secondary zones.

4. Minimize soil disturbance by eliminating intensive mechanical site preparation (root-raking, discing, stumping, bedding).

5. Use prescribed burning as the preferred method for site preparation and control of woody vegetation. Herbicide use should be limited to manual application according to best management practices (BMP) only when fire can not be used.

6. Avoid tying fire lines into known breeding ponds and other seasonal ponds. Plowing around these ponds should also be avoided.

7. During prescribed burning or fire fighting operations, avoid using foam or water from tanks containing foam residue in or around seasonal ponds. Amphibians in general are sensitive to the detergents and chemicals found in foam.

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[1] U.S. Fish & Wildlife Service. April 1, 1999. Endangered and Threatened Wildlife and Plants; Final Rule to List the Flatwoods Salamander as a Threatened Species. Federal Register 62(241): 15691-15704.

September 2, 1999

Progress Summary of
LITERATURE REVIEW AND ANALYSIS OF HERBICIDES EFFECTS ON GROUNDCOVER VEGETATION IN SOUTHERN PINELANDS

by
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We proposed to conduct a literature review of herbicide effects of groundcover species in southern pinelands, mainly for longleaf pine forests. All relevant articles from peer-reviewed journals, technical reports, theses, and agency literature were included in the study. We only considered publications and manuscripts that actually document effects on the groundcover, as opposed to only on midstory hardwoods or pine overstory. We also excluded studies measuring herbicide effects on food lot species. Several variables were obtained from each paper. These include the study site, year/duration of the study, habitat type, presence/absence of a valid experimental design (control and replicates), type of design, number of replicates, herbicide, application rates, and magnitude of the treatment response (% change compared to the control) on species richness, species abundance, and biomass of both target and non-target species. The general conclusions of the authors and any comment about listed species were also reported. Our findings will be reported in table format and analyzed with frequency statistics and, if possible, with meta-statistics.

To date, we scrutinized >100 articles, abstracts, and theses (see bibliography). Publications were obtained through computerized literature searches, traditional literature searches, and by communicating with experts. After careful reading, we retained 35 articles/abstracts/theses that met our primary objective, namely that they reported effects of herbicides on understory species or plant groups in southern pinelands (see Table 1). These studies vary enormously in quality. Most of them are poor because they have a flawed experimental or sampling design, the statistics are incorrect, or the authors do not clearly report on methods and results. For example, the majority of the studies do not report standard deviations or errors, and thus preclude meta-analysis statistics. As our study continues, we may need to drop some publications. Beyond these quality issues, there are some challenges to overcome in order to pursue statistical analyses. 1) Few studies share common treatments because there are many different herbicides and many doses applied. Also, herbicides are commonly used in combinations, thus creating unique treatments. 2) Few studies report on the same variables. A breakdown of studies by variables is shown below:

	Number of studies
Plant species richness	
total:	11
growth form:	3
Diversity indices	
Simpson's Evenness:	4
Shannon-Weaver:	3
No. of genera:	1
Importance value	
by species:	2
by growth forms:	1
Percent cover of species or groups:	17
Density or frequency	
by growth form:	8
by species:	3
Biomass	
by growth form:	2
by total groundcover:	5
Percent change in abundance:	4

3) Some studies measure treatment effects from a few lumped variables (all herbaceous plants), whereas others subdivide treatment effects to the species level. The dependency among variables from the same site violates basic statistical assumptions of parametric statistics. Because these thorny issues are not new in comparative surveys and meta-analyses, we may find ways to minimize their impacts on our general conclusions.

The next steps of our study will be to choose variables (plant species abundance, plant group abundance, plant species richness) and treatments, decide how many we keep from each study, and if we have enough studies to perform any statistics at all. The main results we seek are the average value and standard error of variables in each treatment and the control, and the sample sizes (number of true replicates). These four numbers are then used to calculate treatment metrics for meta-analysis or for simple comparative assessments. We will extract these numbers from all retained studies, which should be a laborious process.

Even after a cursory reading of studies, we were not able to gage the prevalence of negative or positive effects on groundcover plants because the data is too heterogeneous. A general observation is that the positive effects of herbicides may be more common than negative ones when herbaceous plant species are grouped into life forms (e.g., forbs, grasses, herbaceous cover, and so on). This may occur if dominant, and maybe ruderal species (e.g., broomsedge) responded positively to herbicide application. Ruderal species are ubiquitous in these studies because many were conducted in plantations that received a fair amount of site preparation.

Table 1. Retained studies.

#	Author(s)	Treatments	Types of data
3	J. H. Miller, R. S. Boyd, M. B. Edwards (1999)	1 - Hexazinone liquid (Velpar L)-according to directions- Grimsley 2.8 kg ae/ha, Ellington and Hill 3.4 kg ae/ha, McElroy 3.9 kg ae/ha 2 - Hexazinone pellets (Pronone G)-according to directions- Grimsley 2.8 kg ae/ha, Ellington and Hill 3.4 kg ae/ha, McElroy 3.9 kg ae/ha 3 - Glyphosate (roundup) 2.4 kg ae/ha 4 - Triclopyr (Garlon 4) 4.4 kg ae/ha 5 - picloram (Tordon 10K) 3.4 kg ae/ha 6 - 4.5 kg ae/ha dicamba + 4.5 kg ae/ha 2,4 D 7 - control	total species richness richness by growth form Simpson and Shannon's diversity indices total BA, pine BA, hardwood BA (arborescent and non-arborescent) importance values for some species and for growth form categories
6	G. A. Hurst and P. M. Blake (abstract) (1987)	1. **Pronone 5G** - Hexazinone - Aerial application (Broadcast) - 1 lb a.I./ac 2. **Velpar** - Hexazinone - 5 ft. wide banded application (back pack sprayer) 3. Control	total number of genera number of genera by subgroup total plant species - % in common and % only in some plots

9	S. J. Berish (1996)	Hexazinone - Equal concentrations of - 1.68 kg a.i./ha per treatment 1. Velpar (ULW) - granular - 2.25 kg/ha broadcast 2. Velpar L - liquid -1.7 m spot grid - 2 ml per spot 3. Pronone Powerpellet - Brushbullet -1.7 m spot grid (ca. 3534 tablets per ha) 4. control	longleaf pine densities mean DBH of longleaf density estimates of oaks cover estimates (pre-trt), change in cover, mean total groundcover mortality of hardwoods average frequency of occurrence newly recorded species
10	R. S. Boyd, J. D. Freeman, J. H. Miller, M. B. Edwards (1995)	1) imazapyr-at maximum labeled rates (1.1 kg acid equivalent/ha) 2) glyphosate at maximum labeled rates (1.7 kg a.e./ha) 3) hexazinone - per label recommendations - Pronone (1.0 kg a.I./ha for Duggins and Patton sites and 1.7 kg a.i./ha for Robinson site), 4) Velpar (0.7 kg a.i./ha -Duggins site, 1.1 kg a.i./ha - Patton site, and 2.5 kg a.i./ha - Robinson site) 5) control Applied in summer 1985	species richness diversity - Simpson and Shannon-Weiner plot basal area Importance values

11	J. J.. Brooks, A. S. Johnson, K. V. Miller (1992)	1) Pronone (hexazinone) 3.0 lbs. ai/ac 2) Tordon (picloram + 2,4-D) (0.5 + 2.0 lbs. ae/ac) + Garlon 4 (triclopyr) (2.0 lbs. ae/ac) 3) Arsenal (imazapyr) 0.75 lbs. ae/ac (with 0.5% volume-to-volume Induce as a surfactant) no control	mean percent decrease in number of woody stems abundance of vegetation groups -frequency of occurrence plant species diversity-Shannon index, Shannon evenness, mean number of species
12	P. B. Bush, J. Michael, D. G. Neary, K. V. Miller	Hughes Island site: 1.7 kg ai/ha hexazinone-Velpar L Velpar was mixed with water and Polycontrol to provide 370 L/ha carrier ? Barnwell County site: Pronone 10G at 2.8 kg ai/acre, burned and pine seedlings planted	mean percent cover by grasses biomass of grasses dominant forbs % cover of some groups

13	A. F. Clewell and M. E. Lasley	Triclopyr (Garlon 4) prepared as a 0.4 % aqueous solution, added Cidekick-a surfactant added at a rate of 0.75% (surfactant added to dissolve the waxy cuticle of gallberry leaves) 3 trials to test different results all within same site (size?) Trial 1: 3 pairs of transects, at least 30 feet between, treated one of each pair, the other was an untreated control, veg data collected pre-treatment, and at 7 and 12 mo. post-treatment Trial 2: a single 4x100-foot quadrat, pre-treatment veg sampling, whole plot was treated with herbicide, post-treatment veg sampling at 7 and 12 mo. after treatment Trial 3: 3 pairs of 200-foot transects, 22 feet apart, treated one of each pair, the other untreated control. Data collected immediately pre-treatment--no effects of herbicide, then also post-treatment (7 and 12 mo.). Did 5 t-tests for each species and each trial by month and by treatment Test 1: untreated (0 mo.) vs. untreated (12 mo.) Test 2: untreated (0 mo.) vs. treated (0 mo.) Test 3: untreated (0 mo.) vs. treated (12 mo.) Test 4: untreated (12 mo.) vs. treated (12 mo.) Test 5: untreated (12 mo.) vs. treated (0 mo.) ??	number of interceptions by vegetation (by life form and by species) --represents frequency of occurrence and % frequency status of species - I.e., present at month 0 but not at months 7 and 12 number of quadrats species occurred by life form and by specie plant heights by life form

14	W. D. Boyer (1995)	fire + supplemental treatments FIRE burning at 2-year intervals in 1) winter 2) spring 3) summer 4) unburned Supplemental treatments 1) injection of hardwood stems above 1-inch in diameter--with a herbicide 2) cutting just above groundline of all woody stems more than 4.5 feet tall	change in groundcover biomass total green biomass biomass of woody vegetation and other groups litter dry weight
16	W. D. Boyer (1990)	12 treatment combinations FIRE burning at 2-year intervals in 1) winter 2) spring 3) summer 4) unburned supplemental treatments 1) injection of hardwood stems above 1-inch in diameter--with undiluted 2, 4 D amine 2) cutting just above groundline of all woody stems more than 4.5 feet tall	hardwood midstory stems/ac woody stems/ac stems/ac of tree species and arborescent shrubs

17	C. H. Fitzgerald, J. C. Fortson	Field exp 1975: 9 treatments 1) hexazinone only 1 kg/ha, 2) 2 kg/ha, 3) 3 kg/ha, 4) 4 kg/ha, 5) 6 kg/ha, 6) 8 kg/ha, 7) hexazinone at 3 kg/ha plus 0.125% (v/v) surfactant (dodectyl ether of polyethylene glycol), 8) 2 kg/ha hexazinone plus 4.5 kg/ha simazine [2-chloro-4,6-bis(ethylamino)-s-triazine] 9) control Field exp 1976: 16 treatments are arranged factorially 4 levels of hexazinone, 0, 2, 3, 4 kg/ha with/without charcoal root dips, and	Field exp 1975 weed control pine seedling mortality seedling growth after treatment field exp 1976 seedling mortality weed control height growth
18	J. S. Kush, R. S. Meldahl, W. D. Boyer (1999) 2/2 published papers with the same title. Different attributes.	12 treatment combinations FIRE burning at 2-year intervals in 1) winter 2) spring 3) summer 4) unburned supplemental treatments 1) injection of hardwood stems above 1-inch in diameter--with undiluted 2, 4 D amine 2) cutting just above groundline of all woody stems more than 4.5 feet tall	hardwood and pine ba species richness total biomass and biomass of certain groups organic litter

19	D. K. Lauer, G. R. Glover	6 treatments 1-control (SO +HO) 2-first year herbaceous weed control (S0+ H1) 3-first year shrub control (S1 + H0) 4-first year shrub control, first year herbaceous weed control (S1 +H1) 5-repeated shrub control (S2 + H0) 6-repeated shrub control and first year herbaceous weed control (S2 + H1) first year shrub control treatments-initial application of 4-5 lb ae/ac triclopyr in water--total spray vol of 20-30 US gal/ac-preplant broadcast in October-November before planting Repeated shrub control-dormant season basal sprays of triclopyr (6%) and diesel and late season sprays of triclopyr (5%) + glyphosate (2%) in water as needed 1st year herbaceous weed control, broadcast application of 3 oz ai/ac sulfometuron in early spring followed by direct applications of glyphosate (1-2% solution with water) in June-July to control sulfometron-tolerant spp	% cover for major genera and species pine DBH and height means

20	J. L. Michael	7 treatments 1) imazapyr 0.188 lb ai/A 2) imazapyr 0.375 3) metsulfuron methyl 0.063 4) hexazinone 0.5 + metsulfuron methyl 0.063 5) imazapyr 0.188 + metsulfuron methyl 0.063 6) imazapyr 0.375 + metsulfuron methyl 0.063	% weed defoliation of particular species at different sites % loblolly survival
21	J. H. Miller, B. R. Zutter, S. M. Zedaker, M. B. Edwards, R. A. Newbold	Treatments: 1) no treatment, 2) woody control for 5 years, 3) herbaceous control for 4 years, 4) total control-both 2 and 3 woody plant control - Triclopyr (Garlon) and glyphosate (Roundup), directed basal and foliar sprays and basal wipes herbaceous plant control - annual broadcast treatments of the pre-emergent herbicide sulfometuron (Oust) and shielded directed sprays of Roundup	mean cover of groups (Figures) number of genera recorded, common/dominant genera unique genera % of locations where prevalent genera were found, and mean dominance when present & of locations where woody genera were found, mean rootstocks/acre, sum of rootstock heights per acre

24	D. G. Neary, J. E. Smith, B. F. Swindel, K. V. Miller	intensive treatment GNF-w April 1983 recorded 0.56 kg/ha ai sulfometuron methyl in 80 L/ha water carrier, followed by a maintenance application of 0.28 kg/ha in June, woody veg that was not controlled was mowed with rotary cutters in September. In 1984, 2 applications of 2% glyphosate solution with a directed spray technique. From 1985-1989 spot spraying of 2% glyphosate and triclopyr were used to control remaining veg less intensive treatment GNF-e sulfometuron methyl in June 1985 by ground sprayer at 0.42 kg/ha in 200 L/ha of water carrier, October 1986 triclopyr as a 5% solution of ester and a 6.6% solution of amine formulation in 39 L/ha of water carrier	number of plant species - range and average general comments--number of species per transect, amount of bare ground diversity - what metric?
25	D. G. Neary	2x2x2 factorial 3 factors- 1) pine species (slash and loblolly hand planted in January 1983 2) competition (controlled by chemical and mechanical methods-sulfometuron methyl broadcast in 1983 in 2 applications totaling 0.84 kg/ha, lack of woody weed control required rotary cutters, glyphosate applied as a directed spray-2% solution annually in April, triclopyr ester-2% solution used in spot applications to control palmetto) or no treatment 3) nutrient effects (fertilizer-complete-with N, P, K, Ca, S, Mg, Fe, Zn, Cu, and B) added annually in split applications, or no treatment over 3 moisture regimes-irrigation to augment an existing moisture gradient across the replications	gallberry stem density pine heights and diameters

26	W. E. O'Connell and K. V. Miller	Chemical treatment - Pronone 10G rates 1.4-2.3 kg ai/ha Mechanical treatment - shearing residuals with a V-blade and windrowing with root rake Done on 3 different age classes (2, 3, 5 years post-treatment)	mean occurrence for veg groups diversity - Shannon, Shannon evenness, Margalef index mammal and bird data
27	T. C. O'Loughlin, L. R. Nelson, J. D. Walstad, J. H. Breland, J. E. Voeller	Arkansas - Boston Mountains - Velpar 2.0 lb ai/ac, Velpar 1.0 Oklahoma - Oucahita Mountains - Velpar 2.0, Erbon 20.0, Simazine 6.0 + Atrazine 2.0, Propachlor 6.0 Southern Coastal Plain - Velpar 2.0, Erbon 20, Dichlobenil 5.0, Simazine 6.0 + Atrazine 2.0, Propachlor 6.0 Mississippi - Southern Coastal Plain - Velpar 2.0, Erbon 20.0, Simazine 6.0 + Atrazine 2.0, Simazine 4.0 + Atrazine 1.0, Dinoseb 4.5 Interior flatwoods - Velpar 2.0, Erbon 20.0, Simazine 6.0 + Atrazine 2.0, Simazine 4.0 + Atrazine 1.0, Dinoseb 4.5 North Carolina - Pocosin wetlands - black loam soil - Velpar 8.0, Velpar 6.0, Velpar 4.0, Dalapon 8.0 + Atrazine 3.0, Dalapon 12.0 + Atrazine 3.0, Velpar 2.0 Pocosin wetlands - clay loam - Velpar 8.0, Velpar 6.0, Velpar 4.0, Dalapon 8.0 + Atrazine 3.0, Dalapon 12.0 + Atrazine 3.0, Velpar 2.0 Controls for each site	% ground cover of weeds (different weeds for each site)

28	B. D. Shiver, S. A. Knowe, M. B. Edwards, W. N. Kline	34 total treatments 5x5 factorial (25 combinations) of: Picloram - 0, 0.5, 1, 1.5, and 2 lb ae/ac Triclopyr - 0, 0.5 1, 2, 4 lb ae/ac 3x3 factorial (6 combinations not already included in previous combinations) of: Picloram+2,4 D - 0, 0.5+1.85, 1+3.70 Triclopyr - 1, 2, 4 lb ae/ac Hexazinone (Velpar L) - 2 lb ai/ac Glyphosate - 3 lb ae/ac Imazapyr - 1 lb ae/ac All herbicide treatments included 0.5% (v/v) nonionic surfactant (Ortho X-77)	average % control for gallberry, saw palmetto, Vaccinium spp., waxmyrtle, fetterbush, staggerbush, sweetbay response surfaces (figures)

30	B. R. Zutter and J. H. Miller	**Treatments** 1. No Control 2. Woody control 3. Herbaceous control alone 4. Woody and herbaceous control (Total Control) Woody Control Triclopyr (Garlon 4) - 5% solution in water - Applied via backpack as a foliar spray - Applied to hardwood and shrub foliage (Arborescent and Non-Arborescent) - Applied in June of each of the first 3 growing seasons and in the late summer of the first year Herbaceous Control 1. Annual pre-emergent application of sulfometuron (Oust, 4-6 oz product/ac) 2. Directed sprays of Glyphosate (Roundup - 2% solution in water) - Applied twice the first year and once the following 2 years to control herbaceous weeds emerging during summer	pine height, DBH, density, stand ba, stand volume index, % with fusiform rust number of woody rootstocks, sum of rootstock heights, mean rootstock heights plant cover, crown volume index number of arborescent rootstocks
31	R. N. Wilkins, G. W. Tanner, R. Mulholland, D. G. Neary	**Hexazinone** (Velpar-L) - Liquid - Three rates ---0.42 kg/ha ---0.84 kg/ha ---1.68 kg/ha control - Applied with a single back-pack mounted Solo spotgun in a 1X1 m square grid pattern	DBH of oaks, oak mortality ba of wiregrass clumps, dry weight-proportion changes foliar cover and proportion changes

32	R. N. Wilkins, W. R. Marion, D. G. Neary, G. W. Tanner	4 treatments at each site 1. Xeric Sandhill -Hexazinone (Pronone 10G) -0.0, 1.7, 3.4, 6.8 kg a.i./ha (pelletized) -applied with fertilizer spreader 2. Mesic Flatwoods -Hexazinone (Pronone 10G) -0.0, 1.7, 3.4, 6.8 kg a.i./ha (pelletized) -applied with fertilizer spreader 3. Hydric Hammock -Hexazinone (Velpar ULW) -0.0, 1.7, 3.4, 6.8 kg a.i./ha (dry granular) -applied with a modified Solo power blower	mean veg cover and herbicide rate response for species % foliar cover woody and herbaceous diversity (N0, N1, N2) and cover dominance diversity curves
33	R. N. Wilkins (Chapter 2)	4 rates 0, 1.7, 3.4, 6.8 kg ai/ha hexazinone sandhill and flatwoods sites -Pronone 10G hammock - Velpar ULW (due to tall vegetation)	mean cover and rate responses means for woody and herbaceous species diversity (N0, N1, N2) and foliar cover frequency distributions of plant species dominance diversity curves mean foliar cover for each species

34	R. N. Wilkins (Chapter 3)	4 plantations, 2 hexazinone, 2 cleared & debris piled into windrows hexazinone 3.4 kg ai/ha (Velpar L)	mean foliar cover for woody and herbaceous plant species plant diversity (N0, N1, N2 for stand, alpha, W-beta, dis-beta)
35	R. N. Wilkins (Chapter 4)	3 rates of hexazinone and a control (4 treatments) per block Velpar-L - 3 rates (0.42, 0.84, 1.68 kg ai/ha), applied in a spot-grid pattern (1x1m) (and a control)	mean oak mortality oak diameters proportional change in estimated biomass and foliar cover of wiregrass proportional change in foliar cover for 4 understory classes % foliar cover for all understory plant species
37	Provencher, et al.	RCBD: 6 blocks and 4 treatments per block. Treatments are spring burning, ULW hexazinone 2.4 Kg/ha w/ 75% a. I., chainsaw felling/girdling, control (fire-suppression). Treatments applied in spring 1995 after pre-treatment sampling. ULW and felling/girdling burned in winter 1997 for fuel reduction.	species richness %cover of understory groups density of life forms and common species

38	D. G. Brockway, K. W. Outcalt, and R. Neal Wilkins	Treatments: One time application of: 1. Hexazinone granular form, 1.1 kg a.i./ha broadcast 2. Hexazinone liquid, 1.1 kg a.i./ha sprayed in a 2 m x 2 m spot-grid on the ground 3. Hexazinone liquid, 2.2 kg a. i./ha sprayed in a 2 m x 2m spot-grid upon the soil 4. Control which received no herbicide	foliar cover list of plant species plant species richness, Shannon diversity, and evenness (Hill) standing biomass of wiregrass
39	J. D. Haywood, A. E. Tiarks, and M. A. Sword (1997)	**2x2x2 factorial** **Herbicides** **1) None** **2)** Hexazinone (Broadcast Appliec) 1.12 kg/ha and Sulfometuron (Broadcast Applied) 0.21 kg/ha - April 1989 and 1990 followed by 1% Glyphosate in aqueous solution (spot application) Glyphosate (Broadcast Applied) 1.55 kg/ha and Sulfometuron Broadcast Applied) 0.39 kg/ha April 1991 **Fertilizers** 1) None 2) Nitrogen (135 kg/ha) and Phosphorus (151 kg/ha) March 1988 and Urea 42 kg/ha (Nitrogen) in March 1989 **Litter Applied** 1) None 2) Loblolly pine straw applied to 10-15 cm depth	loblolly pine survival, height, DBH, inside-bark volume per tree, volume per hectare, number and length of loblolly lateral roots number per hectare of some veg groups, oven dried weight
40	P. M. Blake (abstract)	1) Aerial broadcast application of hexazinone (Pronone 5G) 1.12 kg ai/ha by helicopter 2) banded application of hexazinone (Velpar L) 1.12 kg ai/ha by backpack sprayer 3) control	total biomass, deer forage, pine heights, pine diameters, species richness

42	D. G. Neary and J. L. Michael (Table 2 - see comments)	4 herbicide treatments, 1 control, replication unknown Arsenal - 1 and 2 lb/acre Escort - 0.33 and 0.66 lb/acre Garlon 4a - 0.75 and 1.50 lb/acre Velpar L + Oust - 0.26 and 0.25 lb/ac Velpar L and 0.39 and 0.25 lb/acre Oust	% control for weed species or groups
43	D. G. Neary and J. L. Michael (Table 3 - see comments)	untreated and treated line transects (216 transects) Oust at 0.5 lb/ac ai, replication unknown	% cover of some species
44	B. R. Zutter, G. R. Glover, and D. H. Gjerstad (1987)	3 treatments CHC - complete herbaceous weed control through first 2 growing seasons OHC - "operational" herbaceous weed control at the beginning of the 1st growing season NHC - no herbaceous weed control CHC - glyphosate applied, then sulfometuron in mid April 1983, retreated with sulfometuron in March 1984, directed sprays of glyphosate as needed after sufometuron application each year OHC - woody weeds clipped at groundline and cut stems wetted with triclopyr ester, Sulfometuron in mid-April 1983 NHC - woody weeds clipped at groundline and cut stems wetted with triclopyr ester	mean height, diameters, biomass, survival of loblolly pine seedlings % herbaceous cover (Figure) Total aboveground standing biomass (figure) % total biomass in weeds and loblolly (Figure) Simpson and Shannon-Weiner diversity % ground cover for several species (Figure) dominant species

45	B. R. Zutter, G. R. Glover, and D. H. Gjerstad (1986)	3 treatments (l, m and h refer to the level of herbaceous veg) low - complete or season long weed control during each of 1st 2 growing seasons Sulfometuron at 0.42 kg ai/ac (mixed with water to get 93 l/ac at 88kg/cm3 pressure) - mid April 1983 Sulfometuron at 0.25 kg ai/ac (mixed with water to get 122 l/ac) - March 1984 Glyphosate 2% solution as a direct spray to hardwoods and weeds emerged since spring herbicide (1983 and 1984) medium - single broadcast treatment at beginning of 1st growing season Sulfometuron at 0.42 kg ai/ac (mixed with water to get 93 l/ha at 88kg/cm3 pressure) - mid April 1983 clipped all woody rootstocks at groundline and wetted surfaces with full strength triclopyr ester -July 1983 high - no weed control clipped all woody rootstocks at groundline and wetted surfaces with full strength triclopyr ester -July 1983	total herbaceous and woody aboveground and root biomass mean height, diameters, biomass, survival, and tip moth incidence for loblolly pine seedlings
46	T. B. Harrington and M. B. Edwards	1) Velpar L - undiluted at 1.7 kg ai/ha in a spot grid with 1-m spacing 2) Garlon - 7% concentration in oil 3) Arsenal, Accord, and X-77 surfactant in water at 0.5, 5, and 0.5% concentrations, respectively 4) control	herbaceous species density and understory cover for groups number of herbaceous species (Figure) mean annual foliar litterfall for pine and nonpine woody veg

47	F. S. Guthery, T. E. Shupe, L. J. Bareiss, C. E. Russell	14 herbicide treatments 1) Oryzalin 2.7 kg ai/ha 2) Oxyfluorfen 1.1 3) tebuthiuron 1.1 4) tebuthiuron 4.3 5) metoachlor 2.7 6) simazine 2.1 7) simazine 4.3 8) hexazinone 4.3 9) hexazinone 8.6 10) diuron 4.3 11) bromacil 0.5 12) bromacil 1.6 13) 1:1 mixture of diuron-bromacil at 0.5 14) 1:1 mixture of diuron-bromacil at 1.6	mean canopy coverage of some plant groups species richness

EFFECTS OF HERBICIDE ON GROUNDCOVER REFERENCES
(* indicates references that we do not have)

*Akesson, N. B. and W. E. Yates. 1987. Effect of weather factors on the application of herbicides. Pp. 334-335 *in* C. G. McWhorter and M. R. Gebhardt, editors. Methods of applying herbicides. Weed Science Society of America Monograph 4.

*Andariese, S. W. and P. M. Vitousek. 1988. Soil nitrogen turnover is altered by herbicide treatment in a North Carolina Piedmont. Forest Ecology and Management 23: 19-25.

*Beckwith, S. L. 1964. Effect of site preparation on wildlife and vegetation in the sandhills of central Florida. Proceedings of the Eighteenth Annual Conference of the Southeastern Association of Game and Fish Commission 18: 39-48.

Berish, S. J. 1996. Efficacy of three formulations of the forest herbicide hexazinone as an aid to restoration of longleaf pine (Pinus palustris) sandhills at Eglin Air Force Base, Florida. M.S. thesis, University of Florida, Gainesville, FL.

*Blake, P.M. 1986. Plant biomass, plant species composition and pine tree characteristics for a banded versus broadcast hexazinone treated pine plantation. M.S. thesis, Mississippi State University, Mississippi State, MS.

Blake, P. M., G. A. Hurst, and T. A. Terry. 1987. Responses of vegetation and deer forage following application of hexazinone. Southern Journal of Applied Forestry 11(4): 176-180.

Borders, B. E. and B. D. Shiver. 1989. Herbicide field studies in forestry: statistical and other considerations. Canadian Journal of Forest Research 19: 768-772.

Boring, L. 1985. Pronone granular herbicide. *In* N. A. Pywell, D. Neary, and B. Law, editors. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.

Bouchard, D. C., T. L. Lavy, and E. R. Lawson. 1985. Mobility and persistence of hexazinone in a forest watershed. Journal of Environmental Quality 14: 229-233.

Boyd, R. S., J. D. Freeman, J. H. Miller, and M. B. Edwards. 1995. Forest herbicide influences on floristic diversity seven years after broadcast pine release treatments in central Georgia. New Forests 10: 17-37.

Boyer, W. D. 1983. Growth of young longleaf pine as affected by biennial burns plus chemical or mechanical treatments for competition control. Pp. 62-65 *in* E. P. Jones, Jr. , editor. Proceedings of the Second Biennial Southern Silvicultural Research Conference. Atlanta, GA. United States Department of Agriculture Forest Service General Technical Report SE 24.

Boyer, W. D. 1987. Volume growth loss: a hidden cost of periodic prescribed burning in longleaf pine? Southern Journal of Applied Forestry 11(3): 154-157.

Boyer, W. D. 1988. Effects of site preparation and release on the survival and growth of planted bare-root and container-grown longleaf pine. Georgia Forest Research Paper #76. Research Division of Georgia Forestry Commission.

Boyer, W. D. 1990. Effects of a single chemical treatment on long-term hardwood development in a young pine stand. Pp 599-606 *in* S. S. Coleman, D. G. Neary, compilers and editors. Proceedings of the Sixth Biennial Southern Silvicultural

Research Conference. Memphis, TN. General Technical Report 70. Asheville, NC: United States Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. Vol. 2.

Boyer, W. D. 1993a. Season of burn and hardwood development in young longleaf pine Stands. Pp. 511-515 *in* J. C. Brissette, editor. Proceedings of the Seventh Biennial Southern Silvicultural Research Conference. Mobile, AL. General Technical Report SO-93. New Orleans, LA: United States Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Boyer, W. D. 1993b. Eighteen years of seasonal burning in longleaf pine: effects on overstory growth. Proceedings of the Twelfth Conference on Fire and Forest Meterology, Jekyll Island, GA.

Boyer, W. D. 1995. Responses of groundcover under longleaf pine to biennial seasonal burning and hardwood control. Pp. 512-516 *in* M. B. Edwards, compiler. Proceedings of the Eight Biennial Southern Silvicultural Research Conference. Auburn, AL. General Technical Report SRS-1. Asheville, NC: United States Department of Agriculture, Forest Service, Southern Research Station.

Boyer, W. D. and J. H. Miller. 1994. Effect of burning and brush treatments on nutrient and soil physical properties in young longleaf pine stands. Forest Ecology and Management 70: 311-318.

*Branch, E. H. 1998. Site preparation effects on small mammal and avian habitat, diversity and composition on the Upper Coastal Plain of South Carolina at 3 and 4 years post-treatment. M. S. thesis. University of Georgia, Athens, GA.

Britt, J. R., R. J. Mitchell, B. R. Zutter, D. B. South, D. H. Gjerstad, and J. F. Dickson. 1991. The influence of herbaceous weed control and seedling diameter on six years of loblolly pine growth—A classical growth analysis approach. Forest Science 37(2): 655-668.

Britt, J. R, B. R. Zutter, R. J. Mitchell, D. H. Gjerstad, and J. F. Dickson. 1990. Influence Of herbaceous interference on growth and biomass partitioning in planted loblolly pine (*Pinus taeda*). Weed Science 38: 497-503.

Brockway, D. G., K. W. Outcalt, and R. N. Wilkins. 1998. Restoring longleaf pine wiregrass ecosystems: plant cover, diversity and biomass following low-rate hexazinone application on Florida sandhills. Forest Ecology and Management 103: 159-175.

*Brooks, J. J. 1992. Chemical site preparation: effects on wildlife habitat and small mammal populations in the Georgia sandhills. M. S. thesis. University of Georgia, Athens, GA.

Brooks, J. J., J. L. Rodrigue, M. A. Cone, K. V. Miller, B. R. Chapman, and A. S. Johnson. 1994. Small mammal and avian communities on chemically-prepared sites in the Georgia sandhills. Pp. 21-23 *in* Proceedings of the Eight Biennial Southern Silvicultural Research Conference.

Brooks, J. L., A. S. Johnson, and K. V. Miller. 1992. Effects of chemical site preparation on wildlife habitat and plant species diversity in the Georgia sandhills. United States Department of Agriculture, Technical Report 50-256. Southern Forest Experiment Station, New Orleans, LA. pp 605-611.

Burton, P. J., A. C. Balisky, L. P. Coward, S. G. Cumming, and D. D. Kneeshaw. 1992.

The value of managing for biodiversity. The Forestry Chronicle 68(2): 225-237.
Bush, P. B., Y. C. Berisford, J. W. Taylor, D. G. Neary, and K. V. Miller. 1995. Operational monitoring of forest site preparation herbicides in the coastal plain: assessment of residues in perched water table. Proceedings of the Southern Weed Science Society 48:115-120.
Bush, P. B., J. Michael, D. G. Neary, and K. V. Miller. 1990. Effect of Hexazinone on groundwater quality in the coastal plain. Proceedings of the Southern Weed Science Society 43: 184-194.
Bush, P. B., D. G. Neary, C. K. McMahon and H. L. Hendricks. 1986. Effect of burning on hexazinone residues in firewood. Proceedings of Southern Weed Science Society 39: 343-352.
*Bush, P. B., D. G. Neary, C. K. McMahon and J. W. Taylor. 1987. Suitability of hardwoods treated with phenoxy and pridine herbicides for use as firewood. Archives of Environmental Contamination Toxicology 16: 333-341.
Cain, M. D. 1997. Cost comparison among chain-saw felling, prescribed fire, and herbicides for releasing natural loblolly and shortleaf pine saplings on a cutover site. Proceedings of the Southern Weed Science Society 50: 201-206.
*Carter, M. C., J. W. Martin, J. E. Kennamer, and M. K. Causey. 1975. Impact of chemical and mechanical site preparation on wildlife habitat. Pp. 323-332 *in* B. Bernier and C. H. Winget, editors. Forest Soils and Forest land Management. Proceedings of the Fourth North American Forest Soils Conference. Laval University, Quebec.
*Cavers, P. B., and D. L. Benoit. 1989. Seed banks in arable land: effects of soil herbicides. Pp.325-326 *in* M. A. Leck, V. T. Parker, and R. L. Simpson, editors. Ecology of Seedbanks. Academic Press, San Diego, CA.
*Chamberlain, E. B. and T. K. Goodrich. 1962. Application of herbicides in southern forests as related to wildlife. Trans. North American Wildlife Natural Resource Conference 27: 384-393.
*Chen, M.-Y. 1974. Effects of herbicides and repeated burns on the understory vegetation loblolly-shortleaf pine forests on hilly terrain. M. S. thesis., Auburn University, Auburn, AL.
*Chen, M.-Y. 1975. Effects of herbicides and repeated burns on the understory vegetation of loblolly shortleaf pine forests on hilly terrain. Dissertation Abstracts 35B:1141.
Clark, J. T. and B. Powell. 1985. The economics of mechanical vs. chemical control of hardwoods on pineland. *In* N. A. Pywell, D. Neary, and B. Law, editors. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.
Clewell, A. F. and M. E. Lasley. 1998. Triclopyr for gallberry reduction at Mississippi Sandhill Crane National Wildlife Refuge, Final Report.
Colbert, S. R., E. J. Jokela, D. G. Neary. 1990. Effects of annual fertilization and sustained weed control on dry matter partitioning, leaf area, and growth efficiency of juvenile loblolly and slash pine. Forest Science 36(4): 995-1014.
Creighton, J. L., B. R. Zutter, G. R. Glover, and D. H. Gjerstad. 1987. Planted pine growth and survival responses to herbaceous vegetation control, treatment

duration, and herbicide application technique. Southern Journal of Applied Forestry 11(4): 223-227.
*De Prado, R. J. Jorrin, and L. Garcia-Torres. 1997. Weed and crop resistance to herbicides. Kluwer Academic, Boston, MA.
Dubois, M. R. 1995. Site Preparation Methods for regenerating southern pines. Alabama Cooperative Extension Service. ANR-275. Auburn University, Auburn, AL.
Dubois, M. R., K. McNabb, and T. J. Straka. 1997. Costs and costs trends for forestry practices in the south. Forest Landowner 56(2): 7-13.
*Easley, J M. 1977. Effects of chemical brush control on vegetation in pine plantations, Kemper County, Mississippi. M. S. thesis, Mississippi State University, MS.
Ezell, A. W., J. Vollmer, P. J. Minogue, and B. Zutter. 1995. A comparison of herbicide tank mixture for site preparation evaluation of treatment efficiency and possible antagonism. Proceedings of Southern Weed Science Society 48: 142-148.
Fitzgerald, C. H. and J. C. Fortson. 1979. Herbaceous weed control and hexazinone in loblolly pine (Pinus taeda) plantations. Weed Science 27: 583-588.
Fitzgerald, C. H., F. A. Peevy, and D. E. Fender. 1973. Rehabilitation of forest land - the Southern Region. Journal of Forestry 71: 148-153.
Glover, G. R. 1985. Growth response of southern pines to control of competing vegetation. *In* N. A. Pywell, D. Neary, and B. Law, editors. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.
Glover, G. R. and B. R. Zutter. 1993. Loblolly pine and mixed hardwood stand dynamics for 27 years following chemical, mechanical, and manual site preparation. Canadian Journal of Forestry Research 23: 2126-2132.
Gottschalk, M. R. and D. J. Shure. 1979. Herbicide effects on leaf litter decomposition processes in an oak-hickory forest. Ecology 60: 143-151.
Green, K. 1982. Forests, herbicides and people. Council on Economic Priorities. New York, NY.
Griswold, H. C. 1984. Pine release with aerially applied liquid hexazinone. Proceedings of the Southern Weed Science Society 37: 230-236.
Guthery, F. S., T. E. Shupe, L. J. Bareiss, and C. E. Russell. 1987. Responses of selected plants to herbicide treatment of disturbed soil. Wildlife Society Bulletin 15: 247-251.
Hance, R. J. editor. 1987. Interactions between herbicides and the soil. Academic Press, New York, NY.
*Hardesty, J. L. and R. A. Moranz. 1999. Draft. Longleaf pine ecosystem restoration in northwest Florida sandhills: issues and recommendations. Summary of the workshop held at Eglin Air Force Base, November 4-6, 1998. The Nature Conservancy, University of Florida, Gainesville, FL.
Harrington, T. B. 1999. Understory vegetation, resource availability, and litterfall responses to pine thinning and woody vegetation control in longleaf pine plantations. Canadian Journal of Forest Research 29: 1055-1064.
Harrington, T. B. and M. B. Edwards. 1996. Structure of mixed pine and hardwood stands 12 years after various methods and intensities of site preparation in the Georgia Piedmont. Canadian Journal of Forestry Restoration 26: 1490-1500.

*Harrington, T. B., P. J. Minogue, D. K. Lauer, and A. W. Ezell. 1998. Two year development of southern pine seedlings and associated vegetation following spray-and-burn site preparation with imazapyr alone or in a mixture with other herbicides. New Forests 15: 89-106.

Harris, L. D. 1978. Effects of forest management practices on wildlife ecology: a list of citations. University of Florida, Gainesville, FL. IMPAC Report 3 (9).

Haywood, J. D. 1994. Tenth-year results of herbaceous weed control in a loblolly pine plantation. Southern Journal of Applied Forestry 18(3): 105-109.

Haywood, J. D. 1995. Prescribed burning and hexazinone herbicide as release treatments in a sapling hardwood-loblolly pine stand. New Forests 10: 39-53.

Haywood, J. D. and A. E. Tiarks. 1990. Eleventh-year results of fertilization, herbaceous, and woody plant control in a loblolly pine plantation. Southern Journal of Applied Forestry 17(3): 135-138.

Haywood, J. D., A. E. Tiarks, and M. A. Sword. 1997. Fertilization, weed control, and pine litter influence loblolly pine stem productivity and root development. New Forests 14: 233-249.

*Hess, F. D. 1987. Relationships of plant morphology to herbicide application and absorption. Pp. 19-36. *in* C. G. McWhorter and M. R. Gebhardt, editors. Methods of applying herbicides, Weed Science Society of America Monograph 4, Champaign, IL.

Howell, D. L., K. V. Miller, P. B. Bush, and J. W. Taylor. 1996. Herbicides and wildlife habitat (1954-1996): an annotated bibliography on the effects of herbicides on wildlife habitat and their uses in habitat management. United States Department of Agriculture Forestry Service Technical Publication R8-TP 13.

*Huang, S. Y. 1988. An economic evaluation of southern pine herbaceous weed control. M. S. thesis. Auburn University, Auburn, AL.

*Huang, S. Y. and L. Teeter. 1990. An economic evaluation of research on herbaceous weed control in southern pine plantations. Forestry Science 36: 313-329.

Hurst, G. A. and R. C. Warren. 1982. Impacts of silvicultural practices in loblolly pine plantations on white-tailed deer habitat. Pp. 484-487 *in* E. P. Jones, editor Proceedings of the Second Biennial Southern Silvicultural Research Conference, United States Department of Agriculture, Forest Service, General Technical Report SE-24.

Jokela, E. J., D. S. Wilson, and J. E. Allen. Early growth responses of slash and loblolly pine following fertilization and herbaceous weed control treatments at establishment. Southern Journal of Applied Forestry. (In Press).

Kline, W. N. and L. K. Hern. 1985. Tordon and Garlon herbicides: new applications and current use recommendations. *In* N. A. Pywell, D. Neary, and B. Law, editors. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.

Knowe, S. A., W. N. Kline, B. D. Shiver. 1987. First year comparisons of mechanical and chemical site preparation treatments in the Georgia piedmont. Proceedings of the Southern Weed Science Society 40: 146-154.

Kush, J. S., R. S. Meldahl, and W. D. Boyer. 1998. Understory plant community response after 23 years of hardwood control treatments in natural longleaf pine (Pinus

palustris) forests. *In* R. G. Wagner and D. G. Thompson, compilers. Third International Conference on Forest Vegetation Management: Popular Summaries. Ontario Min. Natural Resources, Ontario Forest Resources Institute Forest Resource Info Paper No. 141.

Kush, J. S., R. S. Meldahl, and W. D. Boyer. 1999. Understory plant community response after 23 years of hardwood control treatments in natural longleaf pine (Pinus palustris) forests. Canadian Journal of Forest Restoration 29: 1-8.

Lair, K. D. 1998. Influence of herbicides and environmental factors on revegetation success in the Conservation Reserve Program in southeastern Colorado. Dissertation. Colorado State University, Fort Collins, CO.

Landers, J. L., N. A. Byrd, and R. Komarek. 1990. A holistic approach to managing longleaf pine communities. Pp. 135-167 *in* R. M. Farrar, Jr., editor. Symposium on the management of longleaf pine. Long Beach, MS. General Technical Report SO-75; New Orleans, LA: United States Department of Agriculture, Forest Service, Southern Forest Experiment Station.

*Lauer, D. K. and G. R. Glover. 1993. Control of lower coastal plain vegetation with herbicides. Auburn University Silvicultural Herbicide Cooperative Restoration Note 93.

Lauer, D. K. and G. R. Glover. 1998. Early pine response to control of herbaceous and shrub vegetation in the Flatwoods. Southern Journal of Applied Forestry 22(4): 201-208.

*Lautenschlager, R. A. and M. L. McCormick, Jr. 1989. Herbicide release may increase plant species diversity. *In* R. D. Briggs, W. B. Krohn, J. G. Trial, W. D. Ostrofsky, and D. B. Field, editors. Forest and wildlife management in New England – what can we afford? Maine Agricultural Experiment Station. Miscellaneous Report 336.

*Lee, D. V. 1971. The effects of herbicidal hardwood control on wildlife habitat in Louisiana. M. S. thesis, Louisiana State University, LA.

*Leonard, S. A. and R. Dobert. 1996. Herbicide tolerance/resistance in plants: January 1991- June 1996. United States Department of Agriculture, National Agricultural Library, Beltsville, MD.

*Maclean, J. T. 1989. Herbicides, ecological effects. United States Department of Agriculture, National Agricultural Library, Beltsville, MD.

*May, T. A., E. E. May, and M. L. McCormick, Jr. 1982. Plant response to herbicides in clearcut conifer strips. Proceedings of the Northeast Weed Science Society 36: 205-208.

Mayack, D. T., P. B. Bush, D. G. Neary and J. E. Douglass. 1982. Impact on hexazinone on invertebrates after application to forested watersheds. Archives of Environmental Contamination and Toxicology 11: 209-217.

Mayhead, G. J. 1992. Some alternatives to herbicides in British forestry. Quarterly Journal of Forestry. 86(2): 105-112.

Maynard, D. G. 1993. The influence of hexazinone on carbon dioxide evolution and mineralization of nitrogen, phosphorus and sulfur in forest soil. Canadian Journal of Soil Science 73: 433-445.

McComb, W. C. and G. A. Hurst. 1987. Herbicides and wildlife in southern forests. Pp. 28-39 *in* J. G. Dickson and O. E. Maughan, editors. Managing southern forests for

wildlife and fish. United States Department of Agriculture Forest Service General Technical Report S-65.
McLemore, B. F. 1983. Four formulations of hexazinone for controlling hardwoods in pine stands. Proceedings of the Southern Weed Science Society 36: 212-217.
McNabb, K. 1997. Environmental safety of forestry herbicides. Alabama Cooperative Extension System, Auburn, AL.
*Michael, J. L. 1980. Long-term impact of aerial application of 2, 4, 5-T to longleaf pine (Pinus palustris). Weed Science 28: 255-257.
Michael, J. L. 1982. Some new possibilities to control kudzu. Proceedings of the Southern Weed Science Society 35: 237-240.
*Michael, J. L. 1985. Growth of loblolly pine treated with hexazinone, sulfomeuton methy, and metsulfuron methyl for herbaceous weed control. Southern Journal of Applied Forestry 9: 20-26.
Michael, J. L. 1987. Mixtures for weed control in newly planted loblolly pine (Pinus taeda L.). Proceedings of the Southern Weed Science Society 40: 182-186.
Michael, J. L. Vegetation management. Review draft. *In* Effects of forest and grassland management on drinking water quality for public water supplies: A review and synthesis of the scientific literature. Chapter 5. United States Forest Service, Southern Research Station, Auburn, AL.
Michael, J. L. Environmental Fate of herbicides in forest ecosystems and water contamination. Review draft. United States Forest Service, Southern Research Station, Auburn, AL.
Michael, J. L. Glyphosate in forest ecosystems. Review draft. United States Forest Service, Southern Research Station, Auburn, AL.
*Michael, J. L. and W. D. Boyer. 1983. Forestry Herbicides. Forest Farmer 42(8): 6-7.
Michael, J. L. and D. G. Neary. 1985. Response of saw palmetto to three herbicides. *In*: N. A. Pywell, D. Neary, and B. Law, editors. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.
Michael, J. L. and D. G. Neary. 1990a. Fate and transport of forestry herbicides in the south: research knowledge and needs. Pp. 641-649 *in* S. S. Coleman, D. G. Neary compilers, editors. Proceedings of the Sixth Biennial Southern Silvicultural Research Conference. General Technical Report 70. Asheville, NC: United States Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: Vol. 2.
Michael, J. L. and D. G. Neary. 1990b. Use, fate, and risk assessment of forestry herbicides in the southern United States. Pp. 300-311 *in* Proceedings of XIXth IUFRO World Congress. Canadian International Union of Forestry Research Organizations: Vol. 2. New Orleans, LA. United States Department of Agriculture, Forest Service, Southern Forest Experiment Station.
Michael, J. L. and D. G. Neary. 1993. Herbicide dissipation studies in southern forest ecosystems. Environmental Toxicology and Chemistry 12: 405-410.
Michael, J. L. and D. G. Neary. 1995. Environmental fate and the effects of herbicides in forest, chaparral, and range ecosystems of the southwest. *In* M. B. Baker, Jr. and C. C. Avery, editors. Hydrology and Water Resources in Arizona and the

Southwest, Volumes 22-25. Proceedings of the Arizona Section of the American Water Resources Association and the Hydrology Section, Arizona-Nevada Academy of Science. Flagstaff, AR. 114 p.

Michael, J. L., D. G. Neary, J. Fischer, and H. Gibbs. 1991. Metsulfuron in surface groundwater of a north Florida flatwoods. Proceedings Southern Weed Science Society 44: 233-237.

*Michael, J. L., D. G. Neary, and M. J. M. Wells. 1989. Picloram movement in soil solution and streamflow from a coastal plain forest. Journal of Environmental Quality 18: 89-95.

Michael, J. L. and K. L. Talley. 1992. Forest herbicide washoff from foliar applications. Proceedings of the Forty-fifth Annual Meeting of the Southern Weed Science Society; Little Rock, AR. [Champaign, IL]: Southern weed Science Society: 236 p. New Orleans, LA. United States Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Michael, J. L., E. C. Webber Jr., D. R. Bayne, J. B. Fischer, H. L. Gibbs, and W. C. Seesock. 1999. Hexazinone dissipation in forest ecosystems and impact on aquatic communities. Canadian Journal of Forest Research 29: 1170-1181.

Miller, J. H. 1984. Soil active herbicides for single stem and stand hardwood control. Proceedings of the Southern Weed Science Society 37: 173-181.

Miller, J. H. 1987. Chemical vs. mechanical site preparation after fuel wood harvesting. Proceedings of the Southern Weed Science Society 40: 156-166.

Miller, J. H. 1988. Kudzu eradication trails with new herbicides. Proceedings of the Southern Weed Science Society 41: 220-225.

Miller, J. H. 1991. Application methods for forest herbicide research. Pp. 44-59, *in* J. H. Miller and G. R. Glover, editors. Standard methods for forest herbicide research. Southern Weed Science Society, Champaign, IL.

Miller, J. H. 1998. Application variables and their influence on forest herbicide efficacy and selectivity: gaining understanding and control. Proceedings of the Southern Weed Science Society 51: 120-133.

Miller, J. H. 1999. Controlling exotic plants in your forest. Forest Landowner. March/April. p. 59-64.

*Miller, J. H. and L. M. Bishop. 1989. Optimum timing for ground-applied forestry herbicides in the South. United States Department of Agriculture Forest Service, Cooperative Forestry. Atlanta, Ga.

Miller, J. H., R. S. Boyd, and M. B. Edwards. 1999. Floristic diversity, stand structure, and composition 11 years after herbicide site preparation. Canadian Journal of Forestry Research 29: 1073-1083.

Miller, J. H. and M. B. Edwards. 1996. Woody species susceptibility to forest herbicides applied by ground machines. Proceedings of the Southern Weed Science Society 49: 111-119.

Miller, J. H. and G. R. Glover, editors. 1991. Standard methods for forest herbicide research. Southern Weed Science Society, Champaign, IL.

*Miller, J. H. and R. J. Mitchell, editors. 1993. A manual on ground applications of forestry herbicides. United States Department of Agriculture Forest Service, Southern Region and Southern Forest Experiment Station. Management Bulletin R8-MB 21.

Miller, J. H., B. R. Zutter, S. M. Zedaker, M. B. Edwards, J. D. Haywood, and R. A. Newbold. 1991. A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. Southern Journal of Applied Forestry 15(4): 169-179.

Miller, J. H., B. R. Zutter, S. M. Zedaker, M. B. Edwards, and R. A. Newbold. 1995. Early plant succession in loblolly pine plantations as affected by vegetation management. Southern Journal of Applied Forestry 19: 109-126.

Miller, K. V. 1997. Use of herbicides in wildlife management: Forestry and waterfowl. Proceedings of the Southern Weed Science Society 50: 132-133.

*Miller, K. V. and J. S. Witt. 1990. Impacts of forestry herbicides on wildlife. Pp. 795-800 *in* S. S. Coleman and D. G. Neary, editors. Proceedings of the Sixth Southern Silvicultural Research Conference. United States Department of Agriculture Forest Service, General Technical Report SE-70.

*Minogue, P. J., R. L. Cantrell, and H. C. Griswold. 1991. Vegetation management after plantation establishment. Pp. 335-358 *in* Forest Regeneration Manual. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Minogue, P. J., B. R. Zutter, and D. H. Gjerstad. 1988. Pp. 335-358 *in* Soil factors and efficacy of hexazinone formulations for loblolly pine (Pinus taeda) release. Weed Science 36: 399-405.

Mitchell, R. J., B. R. Zutter, M. Perry, C. H. Brewer, D. H. Gjerstad, and G. R. Glover. 1991. Competition among loblolly pine, sweetgum and broomsedge--competition for water in a one-year-old pine stand along a hardwood and herbaceous weed gradient. Proceedings of the Southern Weed Science Society 44: 276-279.

*Moore, W. F. 1996. Effects of chemical site preparation on vegetative, small mammal, and songbird communities in the Georgia sandhills. MS thesis. University of Georgia, Athens, GA.

*Morash, R. and B. Freedman. 1989. The effects of several herbicides on the germination of seeds in the forest floor. Canadian Journal of Forest Research 19: 347-350.

*Morrison, M. L. and E. C. Meslow. 1983. Impacts of forest herbicides on wildlife: toxicity and habitat alteration. Forty-Eight North American Wildlife Conference. 175-183.

Morrison, M. L. and E. C. Meslow. 1984. Response of avian communities to herbicide-induced vegetation changes. Journal of Wildlife Management 48:14-22.

Mullison, W. R. 1972. Ecological effects of herbicides. Down-To-Earth 28: 21-24.

Neary, D. G. 1985. New and old herbicides for weed control in Florida's forests-an introduction. *In* N. A. Pywell, D. Neary, and B. Law, editors. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.

Neary, D. G. 1988. Effect of gallberry on early slash and loblolly pine growth. Proceedings of the Southern Weed Science Society 41: 251-255.

Neary, D. G. 1991. Effects of forestry herbicides on plant species diversity. Proceedings of Southern Weed Science Society 44: 266-272.

Neary, D. G., P. B. Bush, and J. E. Douglass. 1981. 2-, 4-, and 14-month efficacy of hexazinone for site preparation. Proceedings of the Southern Weed Science Society 34: 181-191.

Neary, D. G., P. B. Bush, and J. E. Douglass. 1983. Off-site movement of hexazinone in stormflow and baseflow from forest watersheds. Weed Science 31: 543-551.

Neary, D. G., P. B. Bush, and J. L. Michael. 1993. Fate, dissipation and environmental effects of pesticides in southern forests: a review of a decade of research progress. Environmental Toxicology and Chemistry 12: 411-428.

Neary, D. G. and J. L. Michael. 1985. Herbicides in Florida's flatwoods-efficacy and opportunity. *In* N. A. Pywell, D. Neary, and B. Law, editors. 1985. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.

Neary, D. G. and J. L. Michael. 1996. Herbicides-Protecting long-term sustainability and water quality in forest ecosystems. New Zealand Journal of Forestry Science 26 (1/2): 241-264.

*Neary, D. G., L. A. Morris and B. F. Swindel. 1984. Site preparation and nutrient management in southern pine forests. Pp. 121-144 *in* E. L. Stone, editor. Forest Soils and treatment impacts. Proceedings, Sixth North American Forest Soils Conference, Knoxville, TN.

Neary, D. G., J. E. Smith, B. F. Swindel, and K. V. Miller. 1990. Effects of forestry herbicides on plant species diversity. Proceedings of the Southern Weed Science Society 43: 266-269.

Neill, R. H. 1985. Herbicides by velsicol for forestry uses. *In* N. A. Pywell, D. Neary, and B. Law, editors. 1985. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.

Nelson, L. 1998. Vegetation control for restoration and management of longleaf pine. Proceedings of the Second Longleaf Alliance Conference. Longleaf Alliance Report No. 4. Charleston, S.C. 195 pp.

Nelson, L. R., R. C. Pederson, L. L. Autry, S. Dudley, and J. D. Walstad. 1981. Impacts of herbaceous weeds in young loblolly pine plantations. Southern Journal of Applied Forestry 5: 153-158.

*Nelson, L. R., B. R. Zutter, D. H. Gjerstad. 1985. Planted longleaf pine seedlings respond to herbaceous weed control using herbicides. Southern Journal of Applied Forestry 9(4): 236-240.

*Newton, M. 1967. Response of vegetation communities to manipulation. Pp. 83-87 *in* Herbicides and vegetation management in Forests, Ranges, and Nonrop Lands. School of Forestry, Oregon State University, Corvalis, OR.

Newton, M. and L. A. Norris. 1976. Evaluating short-and long-term effects of herbicides on nontarget forest and range biota. Down-to-Earth 32: 18-26.

*Norris, L. A. 1967. Chemical brush control and herbicide residues in the forest environment. Pp. 103-123 *in* Herbicides and vegetation management. Oregon State University Press, Corvallis, OR.

O'Connell, W. E. and K. V. Miller. 1994. Site preparation influences on vegetative composition and avian and small mammal communities in the South Carolina Upper Coastal Plain. Proceedings of Annual Conference Southeast Association of Fish and Wildlife Agencies 48: 321-330.

O'Loughlin, T. C., L. R. Nelson, J. D. Walstad, J. H. Breland, and J. E. Voeller. 1976. Velpar and other preemergence herbicides for use in establishment of loblolly pine plantations. Proceedings of the Southern Weed Science Society 29: 262-268.

Outcault, K. W. and C. E. Lewis. 1990. Response of wiregrass (Aristida stricta) to mechanical site preparation. Pp. 1-12 *in* L. C. Duever, R. F. Ross, editors. Proceedings of symposium wiregrass biology and management: maintaining groundcover integrity in longleaf pine ecosystems. Valdosta, GA: KBN Engineering, Gainesville, FL.

*Page, H. H., Jr. 1990. Six-year growth response of longleaf pine (Pinus palustris Mill.) seedlings to varying intensities of site preparation treatments. Forest Restoration Reprint No. 4. Smurfit Group.

*Perkins, C. J. 1973. Effects of clearcutting and site preparation on the vegetation and wildlife in the flatwoods of Kemper County, Mississippi. Dissertation. Mississippi State University, Mississippi State, MS.

Polyglase, P. J., N. B. Comerford, and E. J. Jokela. 1992. Mineralization of nitrogen and phosphorus from soil organic matter in southern pine plantations. Soil Science of America 56(3): 921-927.

Polyglase, P. J., E. J. Jokela, and N. B. Comerford. 1992. Nitrogen and phosphorus release from decomposing needles of southern pine plantations. Soil Science Society of America 56(3): 914-920.

Provencher, L., K. E. M. Galley, B. J. Herring, J. Sheehan, N. M. Gobris, D. R. Gordon, G. W. Tanner, J. L. Hardesty, H. L. Rodgers, J. P. McAdoo, M. N. Northrup, S. J. McAdoo, and L. A. Brennan. 1998. Post-treatment analysis of restoration effects on soils, plants, arthropods, and birds in sandhill systems at Eglin Air Force Base, Florida. Annual report to Natural Resources Division, Eglin Air Force Base, Niceville, FL. Public Lands Program, The Nature Conservancy, Gainesville, FL.

Provencher, L., K. E. M. Galley, B. J. Herring, J. Sheehan, J. P. McAdoo, N. M. Gobris, S. J. McAdoo, A. R. Litt, D. R. Gordon, G. W. Tanner, L. A. Brennan, and J. L. Hardesty. 1999. Effects of hardwood reduction on trees and community similarity and sand pine harvest on groundcover vegetation in longleaf pine sandhills at Eglin Air Force Base, Florida. Annual report to Natural Resources Division, Eglin Air Force Base, Niceville, FL. Public Lands Program, The Nature Conservancy, Gainesville, FL.

Provencher, L., D. R. Gordon, K. E. M. Galley, J. L. Hardesty, H. L. Rodgers, J. Sheehan, E. Levine, G. W. Tanner, L. A. Brennan, and K. W. Blandford. 1996. Pre-restoration analysis of plants, invertebrates, and birds in sandhill systems at Eglin Air Force Base, Florida. Annual report to Natural Resources Division, Eglin Air Force Base, Niceville, FL. Public Lands Program, The Nature Conservancy, Gainesville, FL.

Provencher, L., H. L. Rodgers, K. E. M. Galley, J. L. Hardesty, G. W. Tanner, D. L. Gordon, J. P. McAdoo, J. Sheehan, and L. A. Brennan. 1997. Initial post-treatment analysis of restoration effects on plants, invertebrates, and birds in sandhill systems at Eglin Air Force Base, Florida. Annual report to Natural Resources Division, Eglin Air Force Base, Niceville, FL. Public Lands Program, The Nature Conservancy, Gainesville, FL.

Pywell, N. A., D. Neary, and B. Law, editors. 1985. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.

*Rodrigue, J. L. 1994. The effects of chemical site preparation on the diversity and composition of forest vegetation and small mammal communities. MS thesis. University of Georgia, Athens, GA.

*Savage, K. E., B. Truelove, and A. F. Wiese. 1978. Herbicide movement from application sites and effects on non-target species: a summary of regional research accomplishments in the southern United States. Technical committee S-78. Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, MS.

Schultz, D. P. and W. W. Johnson. 1986. Herbicide usage by the U. S. Fish and Wildlife Service. Proceedings of the Southern Weed Science Society 39: 497-498.

Shiver, B. D., S. A. Knowe, M. B. Edwards, and W. N. Kline. 1991. Comparison of herbicide treatments for controlling common coastal plain flatwoods species. Southern Journal of Applied Forestry 15(4): 187-193.

Shiver, B. D., S. A. Knowe, and W. N. Kline. 1990. Comparison of chemical site preparation treatments in the Georgia piedmont. Southern Journal of Applied Forestry 14: 24-32.

Siegal, W. C., C. E. Martus, and C. A. Hickman. 1991. Local regulation of forestry herbicides. Proceedings of the Southern Weed Science Society 44: 360-365.

*Sparling, V. A. 1996. Effects of chemical and mechanical site preparation on the habitat and abundance of birds and small mammals in the upper Coastal Plain of South Carolina. M. S. thesis. University of Georgia, Athens, GA.

*Stalter, R. 1984. Life forms of southeastern sand-hills plants. Bulletin of Torrey Botanical Club 111: 76-79.

Stephenson, G. A. 1985. Du Pont herbicides for use in pine forestry: Velpar, and Oust. *In* N. A. Pywell, D. Neary, and B. Law, editors. 1985. Herbicides for Southern Forestry: Proceedings of the 1985 Annual Spring Symposium. Gainesville, FL. Co-sponsored by the School of Forest Resources and Conservation and the Florida Society of American Foresters. 238 pp.

Sullivan, T. P., R. G. Wagner, D. G. Pitt, R. A. Lautenschlager, and D. G. Chen. 1998. Changes in diversity of plant and small mammal communities after herbicide application in sub-boreal spruce forest. Canadian Journal of Forestry Research 28: 168-177.

*Swindel, B. F., L. F. Conde, and J. E. Smith. 1982. Effects of forest regeneration practices on plant diversity and succession in Florida ecosystems. Pp. 5-16 *in* S. S. Coleman, A. C. Mace, and B. F. Swindel, editors. Impact of Intensive Forest Management Practices, University of Florida, Gainesville, FL.

*Swindel, B. F., J. E. Smith, D. G. Neary, and N. B. Comerford. 1989. Recent research indicates plant community responses to intensive treatment including chemical amendments. Southern Journal of Applied Forestry 13: 152-156.

*United States Department of Agriculture. 1978. Symposium on the use of herbicides in forestry. United States Department of Agriculture, United States Environmental Protection Agency, Washington, D. C.

*United States Department of Agriculture. 1989. Final environmental impact statement: vegetation management in the coastal plain/piedmont. United States Department of Agriculture, Forest Service, Southern Region. Management Bulletin R8-MB-38 Atlanta, GA.

*United States General Accounting Office. 1981. Better data needed to determine the extent to which herbicides should be used on forest lands: report/by the Comptroller General of the United States. Washington, D. C.

Wahlenberg, W. G. 1946. Longleaf pine: its use, ecology, regeneration, protection, growth and management. Charles Lathrop Pack Forestry Foundation and United States Department of Agriculture, Forest Service, Washington, D. C.

Ward, D. B. and C. J. Chapman. 1973. Military herbicide driftage and Florida vegetation. Florida Scientist 36: 109-122.

Webber, E. C., W. C. Seesak, D. R. Bayne and J. L. Michael. 1991. Impact of hexazinone (velpar) on benthic macroinvertebrates and fish in small streams in Coosa County, Alabama. Department of Fisheries and Allied Aquaculture and the Alabama Agricultural Experiment Station.

*Weed Science Society of America. 1983. Herbicide Handbook. 5th ed. Weed Science Society of America, Champaign, IL. pp 268-272.

Wilkins, R. N. 1992. Changes in vegetation following site preparation and understory restoration with the forest herbicide hexazinone. Dissertation. University of Florida, Gainesville, FL.

Wilkins, R. N., W. R. Marion, D. G. Neary, and G. W. Tanner. 1993. Vascular plant community dynamics following hexazinone site preparation in the lower Coastal Plain. Canadian Journal of Forest Research 23(10): 2216-2229.

Wilkins, R. N., G. W. Tanner, R. Mulholland, and D. G. Neary. 1993. Use of hexazinone for understory restoration of a successionally-advanced xeric sandhill in Florida. Ecological Engineering 2: 31-48.

*Witt, J. S. 1991. Forestry herbicides used for site preparation: effects on wildlife habitat. M. S. thesis, University of Georgia, Athens, GA.

Witt, J. S., A. S. Johnson, P. M. Dougherty, K. V. Miller, P. B. Bush, and J. Taylor. Effects of site preparation methods on vegetation structure assessed by two methods.

Wood, J. C., W. H. Blackburn, H. A. Pearson, and T. K. Hunter. 1989. Infiltration and runoff water quality response to silvicultural and grazing treatments on a longleaf pine forest. Journal of Range Management 42(5): 378-381.

Zedaker, S. M. 1991. Biodiversity: boom or bust for forest vegetation management? Proceedings of the Southern Weed Science Society 44: 222-229.

Zutter, B. R., D. H. Gjerstad, A. L. Webb, and G. R. Glover. 1988. Response of a young loblolly pine (Pinus taeda) plantation to herbicide release treatments using hexazinone. Forest Ecology Management 25: 91-104.

Zutter, B. R., G. R. Glover, and D. H. Gjerstad. 1986. Effects of herbaceous weed control using herbicides on a young loblolly pine plantation. Forestry Science 32(4): 882-899.

Zutter, B. R., G. R. Glover, and D. H. Gjerstad. 1987. Vegetation response to intensity of herbaceous weed control in a newly planted pine plantation. New Forests 4: 257-271.

Zutter, B. R. and J. H. Miller. 1998. Eleventh-year response of loblolly pine and competing vegetation to woody and herbaceous plant control on a Georgia flatwood site. Southern Journal of Applied Forestry 22: 88-95.

Zutter, B. R. and S. M. Zedaker. 1988. Short-term effects of hexazinone applications on woody species diversity in young loblolly pine (Pinus taeda) plantations. Forest Ecology Management 24: 183-189.

ABSTRACTS

Blake, P. M. 1986. Diversity, biomass, and deer forage in banded versus broadcast hexazinone in a loblolly pine plantation. Proceedings of Southern Weed Science Society 39: 404.

Brockway, D. G. and K. W. Outcault. 1993. Restoration of longleaf pine/wiregrass ecosystem; plant cover and diversity following hexazinone application. Supplement-Bulletin of the Ecological Society of America 74(2): 175.

Brockway, D. G. and K. W. Outcault. 1994. Plant cover, diversity and biomass in longleaf pine-wiregrass. Supplement-Bulletin of the Ecological Society of America 75(2): 24.

Bullock, F. D., C. W. Dangerfield, and H. L. Merck. 1988. Present and future trends of herbicide use in forestry. Proceedings of the Southern Weed Science Society 41: 256.

Clason, T. R. 1990. Herbicide application benefits natural pine regeneration. Proceedings of the Southern Weed Science Society 43: 274.

Clason, T. R. and D. P. Reed. 1997. Impact of herbaceous weed suppression on root growth of four species of southern pine. Proceedings of the Southern Weed Science Society 50: 94.

Edwards, M. B. and J. H. Miller. 1991. A comparison of site preparation herbicides – five year pine growth. Proceedings of Southern Weed Science Society 44: 256.

Harrington, T. B., P. J. Minogue, D. K. Lauer, and A. W. Ezell. 1998. Pine and competing vegetation responses to site preparation with imazapyr and burning. Proceedings of the Southern Weed Science Society 51: 113-114.

Heinze, J. A., S. M. Zedaker, and D. W. Smith. 1997. Effects of low-input vegetation management on pine-hardwood mixed stands. Proceedings of the Southern Weed Science Society 50: 114-115.

Hurst, G. A. and P. M. Blake. 1987. Plant species composition following hexazinone treatment-site preparation. Proceedings of the Southern Weed Science Society 40: 194.

Hurst, G. A. and W. E. Palmer. 1988. Vegetative responses to hexazinone for site prep. Proceedings of the Southern Weed Science Society 41: 210.

Hurst, G. A. and R. M. Watkins. 1988. Vegetation following imazapyr for site prep. Proceedings of the Southern Weed Science Society 41: 201.

Kline, W. N., B. D. Shiver, and S. A. Knowe. 1988. Second-year comparisons of mechanical and chemical site preparation treatments in the Georgia piedmont. Proceedings of the Southern Weed Science Society 41: 200.

Knowe, S. A. and B. D. Shiver. 1988. Survival and growth of loblolly pine two years after mechanical and chemical site preparation in the Georgia piedmont. Proceedings of the Southern Weed Science Society 41: 199.

Kreh, R. E., S. M. Zedaker, D. W. Smith, and T. S. Frederickson. 1991. Sixth year results of low-input herbicide regeneration alternatives for hardwood-pine stands on the piedmont. Proceedings of the Southern Weed Science Society 44: 239.

Lauer, D. K., R. L. Muir, and G. R. Glover. 1998. Combining herbicide applications with mechanical site preparation. Proceedings of the Southern Weed Science Society 51: 112-113.

Lavy, T. L. and J. D. Mattice. 1987. Fate of Hexazinone in the forest. Proceedings of the Southern Weed Science Society 40: 207.

*Michael, J. L. and D. G. Neary. 1990. Hexazinone cycling in a coastal plain sandhills forest ecosystem. Agronomy Abstracts 82: 337.

Miller, J. H. 1991. Moving towards research standardization in forest vegetation management. Proceedings of the Southern Weed Science Society 44: 238.

Miller, K. V. 1990. Herbicide and wildlife habitat: a review of 35 years of research. Proceedings of the Southern Weed Science Society 43: 202.

Miller, K. V. 1997. Agronomic crops for wildlife food plots. Proceedings of the Southern Weed Science Society 50: 132-133.

Miller. K. V., P. B. Bush, J. W. Taylor, and D. G. Neary. 1990. Herbicide and wildlife habitat: a review of 35 years of research. Proceedings of the Southern Weed Science Society 43: 202.

Miller, K. V., B. R. Chapman, and W. F. Moore. 1997. Wildlife habitat conditions following chemical site preparation in the Georgia sandhills: a 6-year study. Proceedings of the Southern Weed Science Society 50: 114-115.

Miller, K. V., M. D. Whitney, P. B. Bush, and J. W. Taylor. 1989. Wildlife habitat redevelopment following upper Coastal Plain site preparation. Proceedings of the Southern Weed Science Society 42: 303.

Mitchell, R. J., D. B. South, and B. R. Zutter. 1987. Are gains from seedling quality and herbaceous weed control additive? Proceedings of Southern Weed Science Society 40: 207.

Neary, D. G., L. F. Debano, and P. F. Folliott. 1998. Fire impacts on forest soils: a comparison to mechanical and chemical site preparation. Tall Timbers Fire Ecology Conference. Fire and Forest Ecology: Innovative silviculture and vegetation management 21: 24.

Outcault, K. W. and D. G. Brockway. 1993. Response of wiregrass to hexazinone treatments in Florida sandhills. Supplement to Bulletin of Ecological Society of America 74(2): 380.

Schultz, D. P. 1988. Impact of the Endangered Species Act on pesticide usage. Proceedings of the Southern Weed Science Society 41: 36.

Schultz, D. P. 1990. Impact of the Endangered Species Act on pesticide usage. Proceedings of the Southern Weed Science Society 43: 379.

Strickland, R. M. and P. A. Banks. 1987. Herbicide persistence as affected by repeated application. Proceedings of the Southern Weed Science Society 40: 376.

Sung, S. S., D. H. Gjerstad, and J. L. Michael. 1981. Hexazinone persistence in two different types of soils. Proceedings of Southern Weed Science Society 34: 152.

Witt, J. S., A. S. Johnson, K. V. Miller, P. M. Dougherty, and P. B. Bush. 1990. Responses of wildlife food plants to herbicide site preparation in the Georgia piedmont. Proceedings of the Southern Weed Science Society 43: 201.

Yeiser, J. L. 1986. Mechanical and chemical treatments for pine seedling release. Proceedings of the Southern Weed Science Society 39: 191.

Zedaker, S. M. 1998. Fire "and" herbicides? Fire "or" herbicides? What are the issues? 1998. Tall Timbers Fire Ecology Conference. Fire and Forest Ecology: Innovative Silviculture and vegetation management 21: 32.

Zutter, B. R. and G. R. Glover. 1997. First-year response of understory vegetation to application of imazapyr and metsulfuron in a mid-rotation loblolly pine stand. Proceedings of the Southern Weed Science Society 50: 85.

*Zutter, B. R. and D. K. Lauer. 1999. Herbaceous weed control and the establishment and growth of longleaf pine. Proceedings of the Second Longleaf Alliance Conference 4: 177.

THE LONGLEAF ALLIANCE

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Comments From The Director

Dean Gjerstad, Co-Director

We are looking for a new employee. For the past three years, Mark Hainds has been the sole full-time Longleaf Alliance employee. During that span, the workload demands on the Longleaf Alliance have magnified to such a level that we are now in desperate need of additional professional staff support. Our problem has been finding the financial resources to add another person. Although our financial situation remains somewhat tenuous, we felt this move best serves the needs of the Alliance's members. We are searching for an individual holding a master's degree (or bachelor's degree with additional work experience) related to the management and recovery of longleaf ecosystems. Anyone with interest should contact Dean or Rhett.

Funding the Longleaf Alliance continues to be a major concern. Membership fees are an important source of our income but are not sufficient to support staff salaries, travel, postage, publications and other costs of operating a large regional organization. Presently, our major source of income is grants. To receive a grant, we first must write a proposal that, when approved, commits our staff to completing specific work to the grantor. Examples of such work include conducting workshops, producing publications and working with landowners on longleaf recovery projects. During this past summer, we submitted seven grant proposals with all providing funding for a single year. To date three have been funded while the other four are still pending. The good news is that this funding will keep the Alliance financially solvent for another 12 months. The bad news is that we will need to write new proposals next summer to fund the next fiscal year. The negative side of writing so many grants is that it takes valuable time away from the job at hand. When Rhett and I spend 30% or more of our time writing and administering grants, the Alliance suffers. Although we will always submit some grant applications, we are actively pursuing other funding sources that will allow us to spend more time working with the needs of our members and on issues related to longleaf recovery and management.

Rhett and I are excited about the future of the Longleaf Alliance and the recovery of longleaf systems. As the momentum of the longleaf movement continues to grow at an exponential rate, we are energized by the enthusiasm of all who are part of this effort. We appreciate everyone's support and look forward to greater success for our efforts in the new millennia.

Fox Squirrels: Tree Squirrel of the Longleaf Pine Forests

By: Mike Conner, Ph.D., Wildlife Ecologist
Joseph W. Jones Ecological Research Center

Southern fox squirrels are one of the most interesting, yet least understood, animals inhabiting the South's forests. The species appears to be declining throughout its geographical range. As with most declining species, habitat loss is likely driving the fox squirrel population decline.

Southern fox squirrels are strongly associated with open, park-like, pine forests. Consequently, mature longleaf pine forests represent excellent habitat for fox squirrels. Unfortunately, most longleaf pine forests have been lost to agriculture or intensive forestry, and fox squirrel populations appear to have declined as well. Researchers have been studying fox squirrels at the Joseph W. Jones Ecological Research Center since the summer of 1993. However, my personal involvement with the species did not begin until 1997 when workers in my lab began to capture and radio-tag fox squirrels.

Initially, I thought fox squirrels would serve as an easy meal for a variety of predators, but nothing could be farther from the truth. During 2 years of study we have captured and tagged well over 100 squirrels, yet we have only observed a handful of deaths. The fact that we caught a marked squirrel that was captured 4 years earlier, as an adult, is testimony of their longevity in the wild. They do, however, have their enemies, and our best guess is that birds of prey are their major predator. Given the fact that an adult squirrel weighs well over 2 pounds, I anticipate that avian predation is only possible at the talons of the largest birds of prey.

We are also estimating fox squirrel home ranges, the area used by an animal during a specified period of time. By learning how much space a fox squirrel needs during a given year, we hope to be able to estimate the minimum area needed to support a viable fox squirrel population. Although we have not analyzed all of our data, it appears that most fox squirrels have home ranges between 30 – 50 acres. Of course there are a few

homebodies with home ranges as small as 5 acres and a few travelers with home ranges as large as 250 acres.

In addition to monitoring survival and estimating home ranges, we are trying to unravel the subtle habitat features that cause a fox squirrel to want to claim a particular piece of real estate as home. Our data indicate that fox squirrels prefer areas that have scattered oaks or small oak clumps surrounded by a sea of open-canopy pine. If there are a lot of oaks, then fox squirrels will not likely be found. Conversely, if there are no oaks, then there are no fox squirrels. I suppose the old saying, "everything in moderation", applies here. The relationship between fox squirrels and oaks within the longleaf pine forest will be one of our primary interests when data collection is finished and data analysis begins.

The next time you see one of these handsome fox squirrels remember how intimately they are tied to the longleaf pine forests and think about their need for those scattered oaks. I know I will.

Henry Hardtner Award Recipient

Rhett Johnson, Director of the School of Forestry's Solon Dixon Forestry Education Center and Co-Director of the Longleaf Alliance, was recently presented with the inaugural Henry Hardtner Award by the Southern Group of State Foresters at their annual summer meeting in Baton Rouge, Louisiana. Henry Hardtner, a Louisiana native, is often called the "father of Southern forestry" for his pioneering work in developing progressive forest policy at both the regional and national levels in the early 20th century. Beginning in 1898, Mr. Hardtner realized the value of forestland, forest management, and reforestation. Other lumbermen of the time scoffed at his ideas, but he persisted. Although he lacked formal forestry training, he read widely on the subject and soon was crusading for the forestry cause. He was instrumental in the passage of Louisiana's first forestry legislation, Act 113, signed into law by the governor in 1904, which provided for a Department of Forestry, forest fire control, reforestation of denuded lands, and forestry instruction in the public schools. In 1908 he was appointed as the first chairman of the Louisiana Commission for Conservation of Natural Resources. It was appropriate, then, that the Southern Group of State Foresters present the first Henry Hardtner award in Baton Rouge. The award was presented to Rhett, joined at the podium by his wife, Kathy, by John Shannon, the State Forester from Arkansas and the current chairman of the Southern Group of State Foresters, and by Henry Blake, a grandson of Mr. Hardtner. The award recognizes significant contributions to forest sustainability through outstanding assistance to forest landowners. Management chiefs from the 13 southern states in the group choose the winner from among the nominees. Johnson, a forester and wildlife biologist, has been the Director of the Dixon Center since its inception in 1979. He has served as Chairman of both the Alabama Division and the Southeastern Section of the Society of American Foresters and President of the Alabama Chapter of The Wildlife Society and the Alabama Wildlife Federation. He received the Governor's Award as Alabama Wildlife Conservationist of the Year in 1985 and the Southeastern SAF Award for General Excellence in the Practice of Forestry in 1994. Johnson was recognized for his involvement in the development and administration of Alabama's successful TREASURE Forest program since 1980. He has also given hundreds of presentations to landowners over the past 20 years and produced a number of popular and technical publications, including a guide to Threatened and Endangered Species in Alabama for forestry activities. He was instrumental in the development, editing and production of Managing Wildlife, a popular reference text for landowners and professionals published by the Alabama Wildlife Federation. For the past four years, he has also served as Co-Director of The Longleaf Alliance, a regional outreach organization dedicated to the maintenance and restoration of longleaf pine forests across its native range. The Alliance has as its focus assistance to private landowners in planting and management of longleaf pine.

Longleaf Pine Container Nursery Workshop

More than 40 nurseries are presently growing container longleaf pine and the number is growing each year. However, the technology involved in operating container nurseries is complex and, if errors are made, seedling quality suffers, resulting in a poor product sent to the field. In response to the needs of this rapidly expanding industry, The Longleaf Alliance and the USDA Forest Service co-sponsored the first ever longleaf container nursery workshop at Altamaha Technical Institute in Jesup, Ga on September 21-23, 1999. The goal of this workshop was to provide the technical knowledge necessary to produce high quality longleaf seedlings. Approximately 120 nursery owners, managers, vendors, and potential nursery operators from throughout the region attended the meeting. A wide-range of technical topics that can influence seedling quality were covered including irrigation, nutrition, soil mixes, seeding, container types and pests. In response to a strong endorsement by attendees, this workshop will likely develop into an annual affair.

Why was the meeting held in Jesup? Because that is where it all began, thanks to Mr. Howard Waters. Beginning in the early 1980's, Mr. Waters pioneered the

container longleaf industry. By the early 1990's, his nursery was producing nearly 50% of the containerized longleaf grown in the South. Through the years, Howard has helped more than 20 of his friends and neighbors in Jesup and the surrounding area enter into the container longleaf business. Mr. Waters is a very generous man who shares his knowledge freely to those that ask. We thank you, Howard Waters, for your leadership in making containerized longleaf nurseries a thriving industry.

Gulf Coastal Plain Ecosystem Partnership

by Vernon Compton, Project Director

The Gulf Coastal Plain Ecosystem Partnership (GCPEP) is a unique, voluntary, landowner collaboration between Eglin Air Force Base, The Nature Conservancy, Champion International Corporation, Blackwater River State Forest, the Northwest Florida Water Management District and National Forests in Alabama and Florida. Together, these partners manage more than 845,000 acres in one of the most important conservation landscapes in the southeast -- the longleaf pine ecosystem.

Partners	Acres involved
Eglin Air Force Base	463,441
Florida Division of Forestry	189,374
NW Florida Water Management District	97,781
National Forests in Alabama	83,790
Champion International Corporation	7,550
The Nature Conservancy	2,750
National Forests in Florida	1,114

Longleaf pine forests were once the most common upland forest type in the southeastern United States. To date, they have declined by more than 95 percent and are one of the most imperiled ecosystems in the country. In response to this dramatic loss of longleaf pine habitat, seven public and private landowners formed the GCPEP and signed a Memorandum of Understanding in 1996 to conserve and restore this dwindling ecosystem in the Florida panhandle and southern Alabama. The 845,800 acres encompassed by the GCPEP contain more than 20 percent of the remaining longleaf ecosystem. Also contained within this acreage are more than 50 percent of the remaining old-growth stands of longleaf pine. These connected lands, however, include more than just longleaf pine. They contain ecosystems that cut across geographic boundaries, portions of four major watersheds, commercial pine plantations, extensive bottomland hardwood forests, more than 160 rare or imperiled plants and animals and important game and fish populations.

The GCPEP stands as a legacy of the partners' vision and grew out of the desire of local land managers to share resources in a time of dwindling funds and increasing demands. Managers agreed to act cooperatively to share significant challenges, such as management of endangered species, support of natural resource-related jobs and increased recreational demands. Each of the partners also recognize and respect the different management objectives of other partners. Objectives range from intensive forestry to military training, recreation, water resource protection and ecological restoration. However, they all share in common the longleaf pine ecosystem and the needs of local residents.

Under the Memorandum of Understanding, the partners have agreed to develop and implement a cooperative and voluntary stewardship strategy that:

- Sustains native plants and animals
- Conserves and restores ecosystem integrity
- Ensures a continued supply of forest commodities, recreational opportunities, clean water and ecosystem services
- Supports human communities that depend on these resources and services.

To date, the partners have conducted a number of cooperative efforts, such as:

- Joint prescribed fires to restore important ecological areas and reduce hazardous fuels
- Information exchange on forest management techniques and technology
- Monitoring the status and location of rare plants and animals
- Public education on longleaf pine ecosystem conservation and restoration
- Cooperative ecological restoration projects
- Coordinated siting of the Florida National Scenic Trail and other recreational amenities
- Cooperative management of the federally endangered red-cockaded woodpecker and other rare, imperiled species.

The success of any partnership depends on cooperation. So much more can be accomplished by combining the expertise and resources that effectively manage individual properties, while at the same time meet the challenges of sustaining larger ecosystems. The GCPEP is a leading example of how people can work together to achieve common goals. Such cooperation by the GCPEP is evident by the scope of current and completed projects. This same goal of cooperation is shared by The Longleaf Alliance. It is the hope of the GCPEP that these efforts will lead to even better management

practices and, ultimately, increased conservation of the natural resources we all care about.

The partners welcome the involvement of interested private landowners and residents in pursuing the mission of the GCPEP and look forward to the continued cooperation of like-minded groups, such as The Longleaf Alliance.

The GCPEP office is located at the Champion Forest Genetics Research Center in Jay, Florida. If you have questions or would like additional information feel free to contact: Vernon Compton, Project Director, Gulf Coastal Plain Ecosystem Partnership, P.O. Box 785, Milton, FL 32572-0785, 850-675-5760, e-mail: gcpep@bellsouth.net

Florida Wildfire Study Rates Home Protection Measures

The Longleaf Alliance provided technical support and guidance for a recently completed study conducted by Jeff DeWitt, a recent Auburn forestry graduate, for the Interagency Fire Science Team researching many aspects of the 1998 Florida wildfires. Nearly 500,000 acres of woodland were burned, much of it disastrously, and over 350 homes and businesses were damaged and destroyed. It has been the contention of the Alliance and other proponents of prescribed fire that controlled burning can reduce the risk of catastrophic wildfires and prevent disastrous events like those of the summer of 1998 in Florida.

Jeff looked specifically at the effectiveness of home protection strategies in areas where wildfires destroyed significant numbers of homes. As might be expected, houses built using fire resistant materials were indeed less vulnerable to fires. Wooden frame houses were more vulnerable than block or brick homes. The study also indicated that the use of metal soffit vents rather than vents made of other materials was effective in protecting homes from structural damage. This finding supported an earlier study done in Florida in 1987. Predictably, brush- and tree-free areas immediately surrounding houses made them less likely to be damaged by fire. Thirty-foot brush clearance zones and 15 foot tree crown clearance zones appeared to be effective. Well-maintained yards were also less likely to allow fires to damage homes. Earlier studies also indicated that features like wooden privacy fences attached to homes and wooden shingles could contribute to the vulnerability to fire. One of the significant findings of the study was that, although many of these defensive measures were found to be effective and publicized following the 1987 fires, only 16 percent of the surveyed homeowners were aware of them and only half of them had taken action to implement protective measures.

Seedling root and shoot growth of longleaf pine is enhanced with the addition of bacterial amendments to potting media

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Introduction – One possible method to increase longleaf seedling, quality, production, and outplanting survival could be the use of specific biological treatments tailored to forest tree nurseries. Plant growth-promoting rhizobacteria (PGPR) are naturally occurring soil bacteria that are able to aggressively colonize plant roots and stimulate plant growth when applied to roots, tubers or seeds. The use of biological agents as soil amendments to enhance seedling growth, decrease seedling disease or increase seedling survival after out-planting may be an effective cultural practice for re-forestation programs especially in containerized forest-tree nurseries. These studies examined the growth of longleaf pine when sown in soil amended with PGPR treatments.

Methods - Longleaf (P. palustrus) pine seed were sown in containers that had been filled with Pro-Mix® amended with biological preparations based on spore preparations of bacilli PGPR. Treatments consisted of sowing 10 seeds per tree species for each soil amendment in a 40-cell block container (4-cm dia x 9-cm length). Prior to sowing, pine seed was stratified at 4 C for 30 days and surface disinfected with a 30% H_2O_2 for 5 minutes. The resultant seedlings were allowed to grow for 8 week post sowing after which seedlings were harvested and root and shoot characteristics measured using a flatbed scanner and WinRhizo® software. Data was analyzed using Dunnets' test (P=0.05) to compare seedling characteristic between soil amendment and the non-treated blocks.

Results - None of the soil amendments reduced the germination of longleaf pine tested over the non-treated control blocks. Longleaf pine, with its unique grass-stage growth characteristics, was affected by the bacterial amendment with all of the root characteristics significantly larger than the non-treated controls (Table 1).

Discussion - These trials used a non-sterile potting medium, and thus were not set up to monitor some of the biological control mechanisms against pathogens of conifer hosts. These results indicate that PGPR-based soil amendments can be used to enhance seedling growth in the production of containerized forest-tree seedlings.

Other studies have shown that the positive aspects of these rhizobacteria are not evident unless the plant host is under normal field conditions. Such growth promotion in greenhouse-grown containers is promising, the potential for seedling growth-promotion increases when these bacterial strains are used in field situations. Bare-root and containerized forest tree nurseries are at the mercy of soil-borne fungi and their effects on seedling production and quality. The ability to produce disease-free, outplantable seedlings is contingent upon the ability to control the fungi that feed on the seedling root systems. Several methods have been suggested to explain the phenomena of plant growth-promotion when crops are inoculated with rhizobacteria. These include increases in nitrogen fixation, the production of auxin, gibberellin, cytokinin, ethylene, the solubilization of phosphorus and oxidation of sulfur, the extra-cellular production of antibiotics, lytic enzymes, increases in root permeability, and simple competition for the available nutrients and root sites. For each of the 9 PGPR treatments used, one can expect any of the above mechanisms to occur either alone or in concert on pine seedlings. The complexity of such interactions will require extensive studies of a particular strain and pine species used to determine the specific mechanism of growth promotion or growth reduction reported here. It is hoped that with further research specific PGPR soil amendments can be identified for use to promote the growth of the particular tree species desired.

Table 1. Longleaf pine seedling root and shoot characteristics sown in LS213 soil mixture 8 weeks after sowing.

	Longleaf Pine	
Seedling Parameter	Treated	Non-Treated
Total root Length (cm)	39.5*	21.7
Total Root Area (cm2)	1.88*	1.04
Root Surface Area (cm2)	5.92*	3.29
Avg Root Dia (cm)	0.049	0.051
Total Length/Volume(cm/m3)	39.5*	21.7
Total Root Volume (cm3)	0.071*	0.040
Tap Root Length (cm)	7.8*	7.3
Shoot Length (cm)	6.6*	5.7

* Indicates a significant increase in seedling parameter over the non-treated seedlings according to Dunnet's mean separation test, P=0.05, N=40.

New Nurseries

Lanier Nursery is now producing longleaf pine seedlings in Valdosta, Georgia. They are growing container longleaf in a Multipot #6 plugs measuring 6.7" cubic inches in volume. Seedlings cost $140.00/thousand and are sold out for 1999. They use local seed sources and seed from Tenneco Packaging. Call Mike Lansdell at 912-247-8869, Fax: 912-247-0086.

The Wildlife Group, or Beck's Turn Inc. has established a nursery in Tuskegee, Alabama. They are growing longleaf in the 36 mm Jiffy Forestry Pellet. Their current price is $165/thousand and they are sold out for 1999. They have seed from Longleaf Seed Company and Louisiana Forest Seed Company. Call Hunter McDuffie or Wayne Bassett at 800-221-9703 or 800-288-4191. Fax: 334-724-9800. E-mail; becksturf@mindspring.com

Dry Branch Farm is now producing longleaf pine seedlings for sale in Newington, Georgia. They are growing container longleaf in a Stuewe & Sons #6 Superblock. They use Georgia Pacific seed. Their current price is $130.00/thousand and they are sold out for 1999. Call Clint Boykin at 912-857-4675. Fax: 912-857-3709.

Simmons & Sons Seedlings is a new addition in Twin City, Georgia. They are using a Longleaf Seed Company seed source. Their seedlings are $130.00/thousand and they are sold out for 1999. Call Rusty or Heath Simmons at 912-763-3249.

Also in Georgia, Sikes Nursery is now growing longleaf in Screven, Georgia. They are using seed from Southern Seed Company and are growing container longleaf in a #6 Styroblock with 6.3" deep cells. Their current price is $125.00/thousand and they are sold out for 1999. Call Newton Sikes at 912-579-6571.

Membership

Alliance membership trends remain positive. Georgia continues to lead the way with 212 members. Alabama is not too far behind with 170. South Carolina, at 107 members, is the only other state with more than 100 members. The Longleaf Alliance now has members in 22 states and 2 countries, totaling more than 720 memberships. Several members from other parts of the country are absentee landowners with holdings in the Southeast and there are several private and public institutional memberships representing large numbers of individuals.

At what number or time will our total membership level off? How many times will the average member renew? What does it take to retain members for 10 or 20 years? Since both of the co-directors and the one full time employee are new at this ballgame, we do not have the answers yet. We hope that membership continues to climb at the rate demonstrated over the last 12 months. If we maintain this rate of growth, we should reach 1000 members sometime in the next 12-24 months.

What are the benefits of membership in the Longleaf Alliance? The benefits are manifold to landowners and foresters interested in planting or managing longleaf pine. Just a few benefits one may realize from a membership in the Longleaf Alliance include:

#1 **Access to our databases**. Members have free and unfettered access to our *Longleaf Nursery List,* our database of forestry consultants who work with longleaf pine, and our database of tree planters who are experienced planting longleaf pine.

#2 **Assistance finding seedlings**. If seedlings are available, we probably know where they are, how much they cost, and what the seed source is. Although we have run out of leads for the 99-planting season, we will be able to tell you where the most affordable seedlings can be found for next year's planting season. **Members receive priority in notification when we find seedlings in a sold-out market, and we save the best leads for our best members!**

#3 **Neat publications**. First year members receive the Franklin publication, *Stewardship of Longleaf Pine: A Guide for Landowners*. Members renewing the first time receive the Walker/Wiant publication, *Silviculture of Longleaf Pine.* Members renewing the second time receive the beautifully illustrated publication, *A Working Forest; A Landowner's Guide for Growing Longleaf Pine in the Carolina Sandhills.*

#4 **The Longleaf Alliance Newsletter**. Where else can you go to find the newest longleaf container nurseries? Keep abreast of upcoming meetings related to longleaf pine. Read historical letters and accounts from legends in the history of longleaf pine, and much, much more.

#5 **Take pride in knowing that you are supporting the restoration of longleaf pine**. Your membership dues allow us to continue our work throughout the Southeast. Without your support, the Longleaf Alliance would not exist. We need your financial support to travel, print publications, pay the phone bills, conduct research, and promote the restoration of longleaf pine ecosystems, wherever and whenever we have the opportunity.

Recent Longleaf Alliance Presentations

Regeneration and Establishment of Longleaf Pine, Maccleney, Fl. on Aug. 10th and Chipley, Fl. on Aug. 12th.

Forestry Herbicides Meeting, Brewton, AL on Aug. 24th, 1999.

CRP Longleaf Pine Workshop, Troy, AL, Sept 2, 1999.

Society of American Foresters 1999 National Convention, Portland, OR, Sept. 11-15th 1999.

Longleaf Pine Container Production Workshop, Sept. 21-23rd, 1999, Altamaha Technical Institute, Jesup, GA. The first ever workshop focused on growing longleaf pine seedlings in containers.

New Longleaf Videos

By Rhett Johnson

One of Alabama's most popular public television shows, "*Discovering Alabama*", hosted by Dr. Doug Phillips, recently produced and aired two very good videos focussing on the longleaf ecosystem and efforts to restore it across the region. The Longleaf Alliance was a participant and is featured in both videos. These programs, entitled Long Leaf Pine and Long Leaf Ecosystem, are numbers 29 and 30 in the popular series and are available for purchase by writing *Discovering Alabama*, Alabama Natural History Museum, Box 870340, Tuscaloosa, AL 35487-0340, or calling (205) 348-2039. The 25-minute tapes are $10.95 each plus shipping and handling. A limited number are still available from the Longleaf Alliance at the same price. The program airs on Alabama Public Television at 1:00 on Sunday afternoons on most public stations and is repeated later in the week. There are currently 31 *Discovering Alabama* videos available, which are aired on a repeating basis. All are excellent entertainment and very informative. The entire collection may be purchased for $250.00 and makes an excellent gift for a classroom. Teacher's guides are also available.

Another excellent classroom aid has recently come to our attention. A video entitled Fire and the Longleaf, produced by Laurel Hill Press in Chapel Hill, NC, explores plant and animal diversity in fire driven longleaf pine savannas. Narrated by a fourteen-year-old, the video is specifically targeted for elementary grades 4 and 5. My wife's third grade class recently viewed it and, by all accounts, found it entertaining and educational. The video is 12 minutes long, in standard VHS format, and is available from the Laurel Hill Press at P.O. Box 16516, Chapel Hill, NC 27516-6516, telephone (800) 942-6516, or e-mail lhpress@mindspring.com. Cost is $112.95 per copy.